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THE ECONOMICS OF HEAT TREATING

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Abstract

Selection of the source of heat treating is an economic problem, with the final choice dependent upon the economics of the situation, as shown by the over-all cost of the finished product with the different sources of heat. It is not a question of individual process economy, it is a question of over-all economy. The heat chosen must result in the lowest over-all cost, or it will eventually be displaced by some more economical source of heat. The rapid development of industrial electric heating emphasizes the fact that the source of heat for heat treating is not a problem of B.t.u. costs, but is an economic problem involving a study of over-all costs. Such an investigation is well worth while, because it invariably results in discovery of little realized weak parts of the plant practice which influence production costs materially.

SELECTION of the source of heat for the industrial heat treatment of metals is an economic problem. The final choice should be decided by the economics of the situation, as shown by the over-all cost of the product for the different sources of heat. The mere fact that a heat unit in fuel oil may cost two or three times as much as a heat unit in coal does not necessarily indicate that coal is the proper fuel. Oil can be burned much more efficiently than coal at a lower labor cost. If the heat treating department of a plant decides that oil is the cheapest fuel for heat treating, it does not necessarily mean that the company will show greater yearly profit by its

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use. The use of the source of heat apparently the cheapest for the heat treating process itself may result in higher costs for the operations subsequent to the heat treating department, such as: a high percentage of rejections in hardened steel parts; or if inspection is not rigid, in an inferior product which later will mean loss of market; in whole batches of tons of improperly annealed steel piled up around the annealing room clogging production while waiting to be re-annealed; in greater cost of pickling of brass; or trouble in drawing. It is not a question of individual process economy, it is a question of over-all economy.

Among the items which influence over-all cost are: fuel, power, labor, cleaning of product, maintenance, capital charges, storage of raw material and finished product, the dollar value of quality and rejections, straight line production, machining and working conditions. Except where an improvement in working conditions may be of the greatest importance, the decision should be made on no other basis than the total cost, but if the total cost of the two sources of heat seem to be about the same, then, the source of heat most convenient to the specific application should be used. Simple comparison of the B.t.u. cost of electricity, gas, oil or coal gives a very erroneous impression, as no allowance has been made for higher furnace efficiency, lower labor cost, elimination of spoilage; lower machining cost or other items which influence over-all costs, the only cost figure that results in profit or loss. Gas may cost more per B.t.u. than oil or coal, but because of the possibility of more efficient application and greater ease of temperature control may be by far the cheapest fuel. Electricity may cost more per B.t.u. than gas, oil or coal; but because of the possibility of its more efficient application, better temperature control, possibility of straight line production, elimination of rejections, or reduction in machining cost may prove the cheapest source of heat for the manufacturer to use. Many industrial fuel engineers tend to over-emphasize B.t.u. cost in making cost comparisons of various fuels, and when considering their own particular pet fuel in comparison with electricity they seldom get any further. Some inexperienced industrial electric heating engineers over-emphasize the intangible advantage of electric heat. Neither argument can stand up in the face of the over-all economic situation. Lower cost per B.t.u. means nothing if inefficient utilization, higher labor cost and greater spoilage results in less profitable operation, just

as the admitted intangible advantages of electric heat are worthless, if they do not produce a saving in over-all costs and increased profits. If the intangible advantages are real advantages, they will in some way affect costs. The heat chosen must result in the lowest over-all cost, or it will eventually be displaced by some more economical form of heat. The sales enthusiasm of the public utility selling electricity or gas, or the furnace manufacturer, has sometimes resulted in disregard of the economics of the situation, followed invariably by removal of the furnace and loss of the heating load to the source of heat, which a careful, truthful analysis of the whole manufacturing process from the heat treatment operation to shipment of the finished product would have indicated in the first place.

Sometimes an uneconomical application results from a persistent leaning of the manufacturer toward one form of fuel. A few years ago it was not unusual to find a factory using only one source of heat for many different heat treating operations. This tendency is rapidly disappearing, as it has become more generally realized that a heat best suited to one operation may not fit another.

HEAT TREATING IN CONNECTICUT

Local economic conditions in Connecticut are favorable to electric heat treatment and are becoming increasingly favorable to the use of gas. Power costs average from 1.15 to 2 cents per kilowatt hour, marginal power to large users having a high load factor as low as 0.9 cents and night power, that is, all energy used without increase of the day demand 0.9 cents per kilowatt hour. The cost of city gas averages from \$1.00 per thousand cubic feet for the small users down to 65 cents per thousand cubic feet for the large users, and in some parts of the state marginal gas can be purchased at a cost of 55 cents per thousand cubic feet. Oil costs from 7 to 8 cents per gallon at the burner. Bituminous coal is from \$5 to \$7 per ton, and anthracite coal from \$12 to \$14 per ton. Most of our industries are metal working, and many are highly specialized branches of the metal working industry, in which quality is of major importance. It is only natural that there should be a local trend toward the use of electricity and gas for heat treatment, as in general economic conditions provide a sound basis for this trend.

Electric furnaces are in operation for annealing, hardening and tempering steel, the bright annealing of copper and nickel-silver, and

annealing brass. Gas is used for hardening, tempering and carburizing of steel, for annealing of nickel silver shells, and more recently for large production annealing of brass. Oil furnaces anneal, harden, temper and carburize steel and anneal brass and copper in the large rolling mills, and anneal malleable iron. Coal is mainly used only for the annealing of malleable iron and steel, but there are still a few coal-fired carburizing furnaces and brass annealing furnaces in operation. We still have the most ancient of fuels, wood, in use on a large scale for the finishing anneal of brass sheets in the large rolling mills. It appears that this may be replaced by city gas.

ANNEALING OF STEEL

From a production standpoint the two most important applications of annealing in Connecticut are in the ball bearing industry and in the cold-rolled steel industry. Two ball bearing manufacturers use oil for annealing and the third now does its entire annealing with electricity. This manufacturer now has in operation an installed capacity of 1200 kilowatts in eight 150-kilowatt electric furnaces, all of which operate off peak at night so that the furnaces create no additional demand and the cost of power is 9 mills per kilowatt hour. Oil was used previously with a consumption of about 19 gallons per ton of races annealed which, with oil at 8 cents per gallon at the burner, resulted in a heat cost of \$1.52 per ton. The races were loaded on a car and covered with nickel-chromium hoods to prevent decarburization and oxidation. Due to the slow rate of heat penetration a rather long annealing cycle was necessary. A research conducted in a small box type electric furnace indicated that an annealed product could be obtained which would result in considerable saving in the subsequent operations of the plant. It was also found that it would not be necessary to cover the load with hoods. A preliminary estimate indicated that the heat cost for annealing with electricity would be \$2.13 per ton, or 61 cents per ton more than the cost of oil. An experimental 150-kilowatt car type electric furnace was installed, as it was believed that economies in other operations would offset the increased heating cost. This has proved to be the case, as the cost of power and labor is about equal to the former cost of oil and labor. Production has been speeded up by elimination of the hood covering the 3-ton charges of races, and the size of the charge has been correspondingly increased. The annealing cycle has

been reduced from 72 hours to 36 to 48 hours. A large investment in nickel-chromium hoods has been saved which, with alloy at \$1.00 per pound, represented in this particular plant a total investment of \$30,000. A test taken throughout a full charge indicates absolute uniformity. This uniformity has resulted in a big reduction of the subsequent manufacturing cost, because the production of machine departments has been more than doubled on most sizes of races. The piece rate for machining has been cut approximately in half, and a large investment saving has resulted due to reduction of inventory before annealing by two-thirds. The higher investment cost of the electric furnace is more than offset by the elimination of the large investment in nickel-chromium alloy. These results are mentioned simply as a statement of facts, possibly the same results could have been obtained in oil furnaces, but the oil furnaces previously in use were well insulated and apparently properly designed, so that their oil consumption per ton was about the same as that of oil furnaces operated by other manufacturers on the same work. Of course, the heat cost for electric annealing in this case is fairly closely comparable with oil because: first, the cycle of operation permitting night annealing results in a very low power cost; and, second, the elimination of the hood cuts the weight heated approximately in two, and also permits more rapid heat penetration.

In another case a study was made with the view to the use of gas instead of oil as a fuel for annealing bearing races. The oil consumption was approximately 19 gallons per ton of races annealed, as stated in the previous case. The races were annealed in boxes. It was found that gas could not be used for annealing the races, without packing them in boxes or covering them with a hood, because of the danger of decarburization. On this basis gas had to be considered simply as a substitute for oil from a B.t.u. standpoint only. To compete with oil it would have been necessary to sell gas at 35 cents per thousand cubic feet, as the consumption per ton was estimated at 4500 to 5000 cubic feet. At the prevailing rate of 65 cents per thousand cubic feet for a large gas consumer, the cost of annealing with gas would have been double that of annealing with oil. Experiments are being conducted on the open annealing of steel without packing which, if successful, will mean that at a cost of 60 to 65 cents per thousand cubic feet, gas is competitive on a heat basis with oil costing 7 to 8 cents per gallon at the burner. This will result due to the

elimination of boxes and hoods. In the present combustion furnaces for every pound of work annealed there must be heated one pound of box or hood.

Another very important annealing operation in the industries of Connecticut is the bright annealing of cold-rolled sheet steel. The trend from coal to oil and to electricity is shown in these plants in that of three manufacturers using coal five years ago, two are using both coal and oil and a third is using electricity entirely. Furnaces of the ball and truck type are used holding a charge of 5 to 10 tons with the coiled sheets covered by a hood into which producer or city gas is introduced during cooling, or the coiled sheets are packed in iron filings in boxes. The weight of the truck, hood and ball is about equal to that of the work. These plants anneal from 30 to 60 tons of steel per day at a temperature of from 1400 to 1525 degrees Fahr. The cycle takes from 2 to 4 days. The cost of fuel for the coal-fired furnaces averages about \$1.90 per ton and that for the oil-fired furnaces about \$1.60 per ton. The oil-fired furnaces are automatically controlled and maintain a very uniform temperature.

A careful investigation of both the situations showed that the electric furnace operated with alloy pots and hood could anneal steel at an over-all cost of approximately 25 cents per ton lower than the oil and coal furnaces as formerly operated, but that if the use of cast steel pots and hoods was discontinued and alloys substituted, oil annealing was at least 75 cents per ton cheaper. It is of course obvious that this is not a correct application for electric heating except where power is very cheap or fuel expensive. The study of the situation, however, very forcibly brings out the value of investigating your heat treating situation. The average factory seldom makes a complete investigation, except when some electric heating man, trying to sell electric heat, gets them thinking. In this case the investigation has resulted in the use of alloy pots and hoods at a saving to the manufacturer of about \$1.00 per ton of steel annealed, and has also resulted in proving conclusively to the manufacturer that the best way of annealing sheet steel in his particular situation is to use modern automatically controlled oil furnaces with alloy containers.

In the third plant electric furnaces are used entirely for annealing cold-rolled sheet steel and replaced producer gas and coal-fired furnaces several years ago. The capacity now exceeds 1000 kilowatts. No cost data is available, but in this application electric an-

nealing appears to cost from 50 cents to \$1.00 per ton less than the former over-all cost with coal and producer gas. This is due to unusual circumstances, in that, the factory owns its own hydroelectric plant and has available power at a cost of about 0.75 cents per kilowatt hour. As a result of this situation the heat cost for electricity is actually less than the former cost for coal and producer gas. In comparison with their former method of annealing they have a large saving in maintenance cost due, of course, to the use of alloys in the electric annealing furnace. It is also understood that the rate of production has been increased by elimination of rejected 10-ton batches which formerly clogged up production. It is apparent that some savings are being made in this case that are not public knowledge, as expansion continues. A continuous furnace for electric annealing of strip steel has been in operation very successfully for about five years. There is a large maintenance saving which results from conditions which appear difficult to overcome in the combustion furnace previously used.

CARBURIZING

During recent years a considerable number of coal and oil-fired furnaces used for carburizing have been replaced by electric furnaces. Viewed from a general standpoint it seems somewhat difficult to justify some of these installations on an economic basis, but as the number of installations continue to grow it is evident that the individual manufacturer thinks that in getting an improved product over his former method, there results a saving in over-all cost which justifies the investment. Also, in many of these installations, carburizing is conducted only at night which, with the form of power rate prevailing in most of the large cities of Connecticut, results in an energy cost of from 0.8 to 1 cent per kilowatt hour. On this basis the heat cost for electric heating is closely competitive with oil and probably cheaper than coal, when the labor for coal firing is taken into account. On day operation I believe the heat cost of electric carburizing to be double that required in the modern automatically controlled oil furnace. Another factor is the fact that the electric furnaces have in most cases replaced somewhat antique coal-fired furnaces, so that a considerable labor saving has resulted. Also, with the old coal-fired furnace difficulty has been experienced in carburizing small parts due to irregular temperature control. I do not believe this

would apply in any comparison of the electric furnace with a modern automatically controlled oil furnace, on a number of which the temperature curves are as good as those shown by any electric furnace.

Interesting results are now available on the comparative cost of carburizing small pieces in modern insulated rotary drum gas-fired furnaces and rotary drum electric furnaces. In each case solid carburizing compound was used with the average length of heat of from 8 to 10 hours and a temperature of 1690 degrees Fahr.

The gas furnaces were charged with 500 pounds of steel when operating under the above conditions and consumed 16,400 cubic feet of gas per ton of steel, or 8.2 cubic feet per pound. With a marginal cost of gas of 95 cents per thousand cubic feet, the heat cost for carburizing was \$15.60 per ton or 0.78 cents per pound. In the case of electric furnace the charge was larger, being 800 pounds per heat. With other conditions the same as on the gas furnace, the production of carburized pieces per kilowatt hour amounted to 3.24 pounds, or 618 kilowatt hours per ton, and the heat cost for electricity per ton of material carburized was \$7.40 or 0.37 cents per pound, less than half of that in the insulated gas furnace.

In this case to meet the heat cost of the electric furnace under the prevailing local conditions of marginal power at 1.21 cents per kilowatt hour, marginal gas would have to be available at 45 cents per thousand cubic feet. The electric furnace shows a return of 40 per cent on the investment, and additional furnaces are being installed. A study of the over-all efficiencies of the furnaces on this operation, based on the above figures, will indicate the reason why the rotary drum furnaces are an excellent application for electricity. In this case the electric furnace has an over-all efficiency of approximately 24 per cent, and the gas furnace approximately 7 per cent. It is not one of those cases where electricity has been compared with an obsolete fuel furnace, as the gas furnace was modern and purchased within the last year and one-half. The comparatively high efficiency of the electric furnace is due to the fact that there are no flue losses and also end or through metal losses have been eliminated, as the drum does not project outside of the insulated chamber.

HARDENING OF STEEL

In recent years a large number of oil-fired hardening furnaces have been replaced in Connecticut by gas or electric furnaces. In some

localities there is a decided trend toward electricity and in others the use of gas is expanding more rapidly. These changes have been particularly true in the case of industries having a large quantity of production hardening.

A large number of electrically heated lead and cyanide pots of from 15 to 30 kilowatts capacity have been installed for the hardening of small tools, such as, chucks, reamers and cutting tools. One factory has more than 20 of these pots on daily production work. In this plant electric lead pots have resulted in the following benefits in comparison with oil: (1) increased production per man—(2) lower labor cost—(3) better temperature control—(4) much less maintenance cost, the lead containers showing no wear after 3 to 4 years of operation; and (5) a marked improvement in working conditions in the hardening room.

After several years of investigation electric hardening furnaces are being introduced rapidly into the ball bearing industry. Several large plants now either have their hardening department electrified or equipment purchased for so doing. In some of these cases electricity is replacing oil and in one, gas. In the latter case rotary drum gas furnaces were formerly used. At the time the changes were made to electricity about five years ago, production tests over several months showed the cost of electric hardening in a simple box type electric furnace to be \$7 per ton cheaper than the cost in the gas rotary drum furnace, that is, the heat cost for electricity was \$7 per ton less than for gas—with marginal power at 1.7 cents per kilowatt hour, and gas at \$1.12 per thousand cubic feet. On the basis of present marginal cost in this plant with power at 1.21 cents per kilowatt hour and gas at 95 cents per thousand cubic feet, the difference in favor of the electric furnace is still greater. Although electricity costs 28 per cent less than it did five years ago, there has been no change in the rate schedule, the user simply earns a lower marginal rate with increased use. The gas rate, however, was changed, resulting in a reduction of 15 per cent.

The electric furnace eliminated rejections of the races for improper hardening in this plant, and as the complete hardening room is now electrified a considerable saving in labor has resulted. This plant also does all of its tempering in electric furnaces of the forced air circulation type, which replaced gas heated oil baths. With the exception of gas-fired rotary drum furnaces purchased a short time

ago, and which are now being replaced by electric rotary drum furnaces, all heat treating in this plant is performed in electric furnaces—hardening, tempering, annealing and carburizing.

In the other bearing factories where oil is being replaced with electricity, the furnaces are of the rotary hearth type and of the link conveyor type. Formerly box type oil furnaces were used. On these applications electricity costs from 50 cents to \$1 per ton more than oil under the prevailing local conditions, but there is a saving in labor cost of, at least, \$4 per ton of races hardened. These applications of the electric furnace to hardening of bearing races have been made on an economic basis, which result from the case of the application of the electric furnace to conveyor systems and straight line production. In one of these plants approximately 50 tons of steel is hardened each day in the electric furnace. All tempering in these ball bearing plants is performed in electrically heated oil baths or in electric furnaces of the forced air circulation type, with a decided trend in recent installations to the latter.

In the plant of a large spring manufacturer a gas-heated modern belt type furnace is operating very successfully on production hardening of small pieces. An additional unit is being added. Gas in this case replaces oil. This same manufacturer has a large number of gas-fired lead pots for the continuous hardening and tempering of strip steel. These pots operate very successfully and show a considerable saving over the oil pots formerly used, because of lower maintenance cost. This concern uses oil for large production annealing and for some of its hardening and gas for lead pot hardening and tempering. Each time a new application has arisen, they have investigated electricity as well as gas, but for their local situation they feel that gas is considerably more economical than electricity. This situation is accentuated by the fact that they are a comparatively small power user, but a very large gas consumer.

In many cases the industrial plant will be a large power user and a small gas user, or vice versa. Either of these situations results in a very low marginal cost for the commodity used in the greater quantity, and a correspondingly high one for the commodity used in smaller quantity. For example, the concern I have been discussing has a marginal power rate of 1.5 cents per kilowatt hour, but the marginal gas rate is 60 cents per thousand cubic feet so that gas load can be added proportionally cheaper than electric load.

ANNEALING OF NONFERROUS METALS

Oil for annealing in the breaking down operations and wood for the finishing anneal are the basic fuels of Connecticut rolling mills, although some coal is used. The most important development of the past year in rolling mill annealing has been the installation of a large continuous furnace heated with city gas for annealing coiled brass sheets, replacing wood on the finishing anneal. The installation has been so successful that the use of gas for the operation will probably extend rapidly, and under suitable local economic conditions may replace oil for all rolling mill annealing in some mills. A bright anneal is not being obtained, but the finish of the brass is superior to the product of the wood muffles, and the heat cost with gas is only slightly higher than with wood.

Electricity was considered for this operation and it appears has been rejected, because the finish obtained was not as good as with gas. One objection was the effect of grease and dirt on the brass entering the annealing furnace. In the electric furnace the dirt is not oxidized or burnt off as in the combustion furnace and tends to bake onto the brass. This becomes a rather serious matter on the finishing anneal. The control of the atmosphere in the electric brass annealing furnace is a subject worthy of much investigation, because with the same surface finish, electricity is closely competitive with gas on a heat basis in many situations.

While electric furnaces have not progressed very rapidly in large rolling mills in Connecticut, there is a steady increase in the number used for the annealing of brass tubing and shells in specialty plants. The original 350-kilowatt muffle installed in Waterbury in 1923 for tube annealing, has now operated daily 10 to 20 hours for six and one-half years without a coil burn-out or any furnace maintenance expense. Two more furnaces of the same size have been installed in this plant for the annealing of brass tubing. A saving of approximately \$2.50 per ton is made in labor and pickling cost in comparison with the former method of annealing with wood. There is much less oxidation of the brass than in the wood muffle.

Considerable progress has been made in the atmospheric control of electric furnaces for bright annealing copper. Oil continues to be the fuel of the eastern rolling mills, but electricity is still extending rapidly for annealing seamless tubing, coiled sheets and wire. Recently continuous electric furnaces of the tube type have been built

for bright annealing of copper tubing in an atmosphere of steam or some inert gas. Pit type electric furnaces of the retort type are now in use for bright annealing coiled copper sheets in an atmosphere of steam. With neither of these two types of furnaces is a water seal used, which results in a much higher output per kilowatt hour, as high as 20 pounds per kilowatt hour compared with 13 pounds in the most modern water-sealed furnaces, when annealing at a furnace temperature of 1300 degrees Fahr. Cost comparison between water-sealed electric furnaces and water-sealed fuel furnaces, either gas or oil, show a considerable saving in favor of the electric furnace, due to the lower maintenance cost. A properly constructed water-sealed furnace has little maintenance expense, as shown by the fact that two furnaces installed in Waterbury five years ago have operated continuously without coil burn-out or other maintenance expense. It would seem, however, that the continuous tube furnace or the retort pit furnace using steam as an atmosphere has still greater possibilities in reduction of operating cost.

For annealing of nickel silver stamping, installations of electric furnaces continue to increase, but the use of water-sealed furnaces for this purpose does not seem to be extending as rapidly as formerly in this country. The modern gas continuous belt furnace is being considered for this application, because it is possible to produce as clean a product as in the water-sealed electric furnace at a lower cost, depending, of course, on the local economic situation. Continuous belt electric furnaces with a seal of burning city gas at the incoming end and a water seal on the other end are now being built, and produce as clean a product as the continuous belt type gas furnace. Both the electric and gas furnace products require some pickling. Further advance has been made in the introduction of the hydrogen-filled pusher type electric furnace which produces an absolutely clean product and eliminates pickling of the nickel silver. The further development of the hydrogen furnace has interesting possibilities.

In the annealing of nickel silver shells electricity has made little progress, because the water-sealed furnaces available up to now are not well adapted to this class of work. Large gas furnaces have recently been purchased for shell annealing, replacing oil, and a considerable number of gas furnaces have been operating very successfully on this class of work for a number of years.

In this discussion of the economics of heat treating I have confined myself to some of the major applications of Connecticut, first, because I have more accurate information as to operating costs and, second, because I believe that the type of installation we have in Connecticut resembles those in which you are interested more so than some of the large heat treating jobs of the middle west. Possibly I have dwelt more upon electric heat treating than upon the use of fuel. This is not because I am more interested in the promotion of electric heating, but because its development is more recent and each application serves to emphasize the fact that the selection of the source of heat for heat treating is an economic problem involving a study of over-all costs.

From its beginning in the year 1889, forty years ago, the application of electric heating to industrial work has proceeded in an entirely logical manner along economic lines in accordance with the requirements of the industrial world. Modern civilization could not have reached its present stage of mechanical development without the product of the electric furnace. Electric heating in its development has passed through three broad periods; from 1889 to 1900 electric melting; from 1900 to 1918 electric melting; and from 1918 to date, what is now called industrial electric heating. Starting with high temperature processes which can be conducted economically only in the electric furnace, electric heating has progressed through the whole temperature range of metallurgical and industrial processes down to simple drying and baking at low temperatures.

From 1889 to 1900 electric heat was used almost solely for smelting processes, such as the manufacture of calcium carbide, the smelting of refractory ores to produce ferro alloys, the manufacture of artificial abrasives, and in the electrolytic production of aluminum, all of which are processes which can be conducted satisfactorily and economically only with electric heat.

Carbide does a large part of the welding of the world. It lights the mines and is now the basis of many chemicals. The 200-kilowatt carbide furnace of 1889 has now grown to 10,000 kilowatts.

The effect of electric furnace ferro alloys and artificial abrasives on modern industries has been very marked. It has been stated that the electric furnace made the motor industry and built Detroit with ferro alloys and artificial abrasives. Every motor car contains an appreciable quantity of electric furnace product ferro alloys in

its steel. Without them we would not have our high powered small light weight cars, airplanes, high speed cutting tools, stainless steel, electric heat treating furnaces or domestic heating appliances. With the exception of ferromanganese none of these ferro alloys can be produced as satisfactorily or economically in combustion furnaces as in the electric arc furnace, and during recent years a large part of the ferromanganese used in this country has been made in the electric furnace. Our modern alloy steels result from the high grade ferro alloys of uniform composition produced cheaply in the electric furnace.

Aluminum, the fourth product of the early period of development of electric heat, has not only been a metal of equal industrial importance to ferro alloys and abrasives but now enters into our yearly domestic life more than any other element except iron. Although it is one of the most common elements in the world, its wide occurrence was useless until the electrolytic action of the direct current in a smelting furnace kept hot by resistance electric heating produced aluminum at a cost of less than one quarter its former cost and made it available for industrial use.

Thus, this early development of electric heating and electric smelting with the production of materials, forming the very basis of modern industry, was entirely along economic lines.

In 1900, the second, or melting period of development of industrial electric heating began with the invention of the Heroult electric furnace—the prototype of most modern steel melting furnaces, and progressed very rapidly in Europe but slowly in this country until 1915 when war requirements of high grade alloy steel caused a tremendous increase in the use of electric melting furnaces in our steel mills and foundries. The electric furnace is now established as the most economical method of manufacture of tool steel, and 95 per cent of the tool steel produced in this country is now made electrically. The economics of the tool steel situation are all with electric furnaces as the saving amounts to \$10 to \$15 per ton in comparison with the old crucible furnace. Recently a new type of furnace, the high frequency electric furnace, has been applied to the production of these steels with some very remarkable results in improvement of quality at a cost only slightly higher than that of the electric arc furnace. In the foundry the electric arc furnace has practically driven the small converter out of the field, because of the 10 to 15

per cent higher metal recovery and ability to use an all scrap charge without pig iron, which means from \$10 to \$15 per ton lower production cost.

Investigations of the United States Bureau of Mines made in 1913 showed that large metal losses were taking place in the established methods of melting brass in combustion furnaces. The electric furnace was suggested, but there was no suitable type available. Simultaneously there were developed three types of brass melting furnaces, the carbon resistor furnace, the vertical ring induction furnace and the rocking arc furnace. Because of its higher operating cost the carbon resistor furnace has dropped out of the picture. The vertical ring induction furnace is used almost universally in the rolling mill, almost all of the rolling mill brass melted in the United States today being melted in this furnace, and the rocking arc furnace is the favorite of the foundry. Neither of these types of electric furnaces is satisfactory to the small foundry operation. The recent developments of the rotary drum gas furnace fills an important need in the small foundry which has never been taken care of by the electric furnace. Due to the high investment cost of the electric furnace it does not usually pay to make an installation where the daily production is under 3000 pounds. It is doubtful whether this new gas furnace will prove competitive with the modern induction furnace in the rolling mill.

Electric melting has progressed rapidly in the brass industry because the economics of the situation demand it. In Waterbury alone electric brass melting saves over \$1,000,000 per year. This saving is accomplished because the over-all cost of electric melting is about \$5 per ton less than the former coal-fired pit melting, due to the saving in labor and lower zinc loss. Under present conditions the power cost per ton of metal melted is actually considerably less than the fuel cost and the lining cost of the electric furnace is a little less than the refractory and crucible cost of the pit fire. It is an economic application of electric heating.

We are now in the third stage of application of electric heating to industries, that is, heat treating and low temperature applications. This development really began about 1912 with construction of the granular carbon resistance furnace by Bailey. It was not until 1915 that the possibility of using nickel-chromium alloys as resistors for industrial heating devices or for heating large electric furnaces was

realized, although these alloys had been patented in 1904. Undoubtedly the successful construction of large electric heat treating furnaces heated by granular carbon resistors was the catalytic agent which put the best brains of the electric world to work on the application of metallic resistors to industrial heating.

Since the construction of the first metallic resistor electric heat treating furnaces, about 10 years ago, great improvements have been made, so that today the electric furnace is firmly established as a means of heat treating under suitable local economic conditions. It will retain this position only so long as it is applied economically. In any situation if any improvement made in construction of oil and gas furnaces results in the lowering of over-all cost, the economic situation will compel the displacement of the electric furnace by these fuel furnaces.

Today, more than ever, metal working industries realize the importance of heat treating in their operations. It is now generally understood to a greater extent than ever before that a comparison of costs of sources of heat on a thermal basis means nothing without a complete investigation of over-all costs. Even if such an investigation leads to no change in the source of heat, I believe it well worth while, because it invariably results in the discovery of little realized weak parts of the plant practice which influence production costs materially. Selection of the source of heat for heat treating is an economic problem with the final choice depending on the local economics as shown by the over-all cost of the finished product with the different sources of heat.

DUPLEX PRACTICE

BY J. E. CARLIN

Abstract

This article was prompted by the fact that the duplex process embodies two features whose successful utilization will very materially assist in changing the basic open-hearth process from an art to a science; these two features are change of slag by the use of a tilting furnace and de-oxidation with carbon.

It is quite generally accepted that the reaction



represents the mechanism by which carbon is oxidized in the basic open-hearth furnace. The oxidizing mechanism is such that considerable ferrous oxide is introduced into the metal; its presence is harmful to the finished steel and it is more or less completely removed by such reducing agents as silicon and aluminium. The reduction products, silica and alumina, are solid refractories and their presence is probably more harmful than the ferrous oxide.

Oxidation is always accompanied by reduction and the possibility presents itself of utilizing both principles in the same reaction. As long as the slag contains iron oxide, oxidation is predominant; if the oxidizing slag is replaced by a neutral one made up of lime and spar, it should be possible to reduce the remaining oxide by the residual or additional carbon.

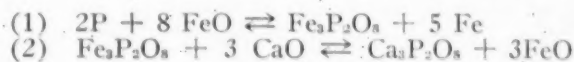
THE duplex process which combines the rapidity of the acid Bessemer process with the dephosphorizing power and close control of the basic open-hearth process is interesting both from a chemical and an economic viewpoint. It is carried out usually in a tilting Talbott furnace of 100 to 300 tons capacity and was designed originally for the rapid manufacture of low carbon steel of tonnage quality. Certain refinements have been developed recently and the process is now capable of producing steel of any carbon content, of a quality which approaches, and with good practice, rivals that of the regular basic open-hearth process. In common

The author, J. E. Carlin, member of the society, is on the metallurgical staff of the Union Drawn Steel Co., Beaver Falls, Pa. Manuscript received January 17, 1930.

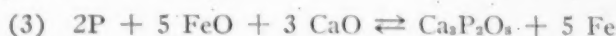
with the majority of steel-making processes two factors of greatest importance are the slag and the charge.

THE SLAG

In its function and composition the slag differs radically from that of the regular basic process. The most important slag function of either process is the elimination of phosphorus. The mechanism of this elimination has been shown¹ to consist in the oxidation of phosphorus to ferric phosphate and its subsequent neutralization by lime, according to the following reactions:



The algebraic sum of reactions (1) and (2) gives reaction



which means that the oxidation and permanent removal of phosphorus depends upon an excess of both ferrous oxide and lime, and is further favored by low temperatures.

In the pig and scrap method of the regular basic process, a charge of approximately 50 per cent pig iron, 50 per cent scrap is generally used. Practically all of the scrap is of basic open-hearth manufacture with a phosphorus content of approximately 0.015 per cent. The pig iron used is produced from basic ore and contains around 0.225 per cent phosphorus. In a 200,000-pound charge there would be approximately 240 pounds of phosphorus to be removed.

In the duplex process the charge may consist of duplex metal blown entirely from basic pig iron. The phosphorus content of a 200,000-pound charge would be approximately 450 pounds. The slag of the duplex process, therefore, must be capable of oxidizing and removing approximately twice as much phosphorus as that of the regular basic process. The iron oxide content, therefore, is of necessity comparatively high and for this reason sulphur elimination is retarded except when unusually large amounts of lime are added.

Immediately after the tap, the slag for the next heat is made up. This is done by charging alternately roll scale and burnt lime. The furnace is not emptied completely and the heat of the residual metal serves to fuse the scale and lime into a homogeneous mass. The amounts of scale and lime charged have been determined by

¹C. H. Herty Jr., Bulletin 34, Bureau of Mines.

experience and vary with the quality desired and to a certain extent with the charge.

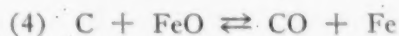
THE CHARGE

Unlike the regular basic process the charge is usually completely molten and consists of duplex metal followed by approximately 10 to 20 per cent of its weight of pig iron. Duplex metal is the name given to the product of a Bessemer blow which has not been deoxidized or recarburized by manganese.

In the acid Bessemer process, it is possible to remove permanently practically all of the carbon, manganese and silicon initially present in the pig iron. Due to the absence of a basic slag, phosphorus and sulphur are not eliminated and it is found that their percentage composition actually increases due to oxidation of the iron. This increase amounts to approximately 10 per cent. Owing to the extreme rapidity of the process, it is very difficult to stop the blow at a predetermined carbon content, and it is the usual practice to blow full, which means that the resultant product contains approximately 0.05 per cent maximum carbon, 0.10 per cent maximum manganese and the phosphorus and sulphur content approximately 10 per cent higher than that of the initial pig iron. Duplex metal may be produced from either basic or Bessemer pig iron, the only difference being in the phosphorus content.

The duplex metal is charged into the furnace from ladles of approximately twenty-five tons capacity as this weight corresponds to that of a Bessemer blow. The ladles may be either of the lip or spout variety, which means that if the lip type is used, the duplex metal is poured from the top, while if the spout type is used, the metal is teemed from the bottom. A slag consisting of silica, iron and manganese oxides is produced in the Bessemer process, and in tilting the converter at the tap, a considerable amount of slag is of necessity run into the ladle with the metal. If the lip type of ladle is used various amounts of this objectionable slag are charged into the furnace.

The amount of duplex metal charged is determined by the capacity of the furnace. As soon as the charge is complete, approximately 10 to 20 per cent of its weight of pig iron is added. This causes a violent reaction owing to evolution of carbon monoxide according to the following reaction.

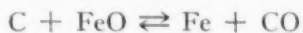


The violence of the boil is determined by the degree of oxidation of the duplex metal, its temperature and the temperature of the pig iron. As a result of the vigorous reaction the metal and slag are intimately mixed and the high concentration of ferrous oxide together with low silica insures a rapid and practically complete oxidation and removal of phosphorus.

At this point an interesting comparison with the regular basic process suggests itself. In the regular process, iron oxide in the form of iron ore is used to oxidize an excess of carbon, while in the duplex process an excess of carbon in the form of molten pig iron is used to reduce the iron oxide which saturates the duplex metal.

At the present time, it is not practicable to determine the degree of oxidation of the duplex metal—consequently the amount of pig iron necessary to effect complete deoxidation and to provide for a slight excess of carbon is more or less guess work. The rate at which the iron oxide in the metal is reduced by the carbon of the pig iron depends upon the concentration of each and upon the temperature. As soon as carbon is present in the metal, it is also acted upon by the iron oxide in the slag. The diffusion and reaction rate is proportional to the concentration of the iron oxide in the slag, the viscosity of the slag and the temperature. Oxidation of carbon by the ferrous oxide already present in the metal and by that which diffuses from the slag proceeds simultaneously. The rate at the start or until the ferrous oxide and carbon in solution come near to equilibrium is exceedingly rapid. The intensity diminishes as equilibrium is approached and when a medium uniform boil is present over the bath, it may be assumed that the carbon and ferrous oxide in solution are practically in equilibrium and that the reaction proceeds due only to diffusion of ferrous oxide from the slag. The importance of regulating and controlling the amount of ferrous oxide in the duplex metal and in the slag cannot be overestimated. The composition of the slag is, of course, easily controlled but that of the duplex metal is difficult. A duplex metal heat may be blown in a comparatively short space of time and unless the flame is very carefully watched at the end, overblowing to a great extent is possible. The ideal procedure would be to determine the extent of oxidation scientifically and calculate the amount of carbon or pig iron necessary. This is not practicable as yet and the next best procedure is to add an amount of pig iron which is greatly in excess.

This may be done by checking the carbon on a number of heats as soon as the violent reaction has subsided. This will give a rough indication of how much pig iron is necessary to leave an excess of carbon which can be oxidized slowly by the slag. It happens sometimes that due to excessive overblowing or insufficient pig iron, or both, the fracture test at the end of the heavy boil shows the carbon to be extremely low. This means that the ferrous oxide in the metal was sufficient to oxidize all of the carbon without the help of the slag. A heat tapped in this condition even though sufficient coal or coke is added to bring it within the carbon specification, will be extremely wild, and is indicative of very poor practice. Good practice necessitates a careful watch of the violence of the boil and toward the end of the heat, if the carbon is dropping rapidly, more pig iron should be added. The duplex process offers an exceptional opportunity to study the rate of the reaction.



Although carbon is eliminated according to this reaction in both the regular and the duplex processes, in the regular process carbon elimination, except when ore is added, depends upon diffusion, which in turn depends upon temperature, composition and viscosity of slag.

Exact conditions of slag viscosity and temperature, from heat to heat, are difficult to duplicate and maintain, and to study the reaction on a practical scale, it is necessary to provide a system which allows a knowledge of the temperature, and the concentrations of both ferrous oxide and carbon in the metal at the start of the reaction. These concentrations should be such that the reaction is a considerable distance from equilibrium at the start. Such conditions would insure freedom from slag viscosity complications.

At the present time, it is impossible to determine the temperature with an instrument, but it may be assumed constant within a fairly close range. In the duplex process the oxygen content of the metal may be determined and the carbon content calculated from an analysis of the pig iron and the total volume of the metal. In this manner slag viscosity may be disregarded for it may be assumed that until equilibrium between carbon and ferrous oxide in the metal is closely approached diffusion of ferrous oxide from slag to metal is of little importance. Thirty or forty points of carbon may be eliminated in a comparatively short space of time, and during this period,

the temperature may be assumed to remain constant. If the carbon and oxygen contents are determined at regular intervals and the results plotted on a time-carbon-oxygen diagram, interesting and practical information may be obtained. Due to the silicon and manganese content of the pig iron, the results obtained would be relative, but inasmuch as the concentration of manganese and silicon of the bath as a whole would be small, the results would not be affected from a practical standpoint.

FINISHING THE HEAT

Ideal finishing conditions include—

- (1) Equilibrium between slag and metal with respect to iron oxide.
- (2) A judicious use of silicon and manganese, (determined by carbon content) to effect deoxidation as nearly as possible and to promote fluxing and elimination of the solid deoxidation products.
- (3) A tapping technique which will provide a ladleful of steel before the slag comes.
- (4) A minimum amount of slag covering metal in ladle.
- (5) Dilution of the ferrous oxide concentration of the slag in the ladle by the use of burnt lime and spar.
- (6) A temperature high enough to warrant holding the heat in the ladle.

Economy will not permit tapping the heats at equilibrium, but if the amount of scale charged is regulated with due respect to the charge, to the amount of pig iron added, and to the carbon desired, ideal conditions will be approached.

If it is considered that the carbon content and temperature determine approximately the amount of ferrous oxide in the metal, a ratio of manganese to silicon may be calculated which will provide for maximum deoxidation and optimum fluxing of the deoxidation products.

Care and practice in plugging the tap hole will insure that the next heat will be tapped through a hole large enough to keep the steel at the right temperature, and yet small enough to hold the slag back until the ladle is nearly full. If an early slag occurs wildness in the ladle and excessive loss of carbon, manganese and silicon results.

When the heat is in the ladle with its blanket of slag, diffusion of iron oxide from slag to metal takes place just as it does in the furnace. In theory, the rate of diffusion does not depend upon the

amount of slag, but in practice it is found that the amount is very important, especially when the iron oxide content of the slag is high. For this reason the amount of slag in the ladle should be kept at a minimum. It is possible to correct the harmful effects of a large amount of highly oxidizing slag by the addition of a mixture of burnt lime and spar. This mixture should be added after the slag comes. Its purpose is to dilute the concentration of ferrous oxide thereby checking diffusion.

A high finishing temperature serves to decrease the amount of ferrous oxide in solution for a given carbon content, and to decrease the viscosity of the metal. This decreased viscosity provides the best conditions for fluxing and eliminating the deoxidation products. If the above practices have been followed, the various reactions should be in equilibrium and if the temperature is high enough to warrant holding the heat in the ladle this will promote complete diffusion and equalization of the ladle additions and elimination of the deoxidation products.

DEOXIDATION OF THE SLAG

The superiority of electric furnace steel may be assumed to be due to the fact that the finishing slags are neutral or reducing. In electric furnace practice, when the carbon has reached the desired percentage, the oxidizing slag is raked off and a new slag made up of lime and coke dust is charged. By this method, equilibrium between slag and metal with respect to iron oxide is assured, and sulphur elimination to a minimum is possible. Slag deoxidation is not attempted as yet in basic open-hearth practice, as slag volume in this process is very large and the phosphorus and sulphur content of the slag is generally much higher than in electric furnace practice.

The tilting open-hearth furnace offers the possibility, however, that this ideal may be realized in time. With the tilting furnace it is possible to reduce the slag volume to a large extent. Suitable additions of spar and lime could then be made so that the iron oxide, phosphorus and sulphur contents would be reduced materially with very little danger of the phosphorus and sulphur returning to the metal. All ladle additions could then be made in the furnace, with a very small loss of manganese, silicon or other ferro alloys.

This procedure could be worked up on tilting furnaces of around fifty tons capacity, and, if practical, applied to the large furnaces which are in wider use.

ANNEALING OR SOFTENING OF NITRIDED STEELS BY CHEMICAL DECOMPOSITION OF THE NITRIDES

By WILLIAM J. MERTEN

Abstract

This paper describes the method of softening the nitrided case of aluminum-molybdenum and aluminum-chromium nitriding steels by chemical decomposition of the nitrides in a fused sodium-potassium chloride bath (50/50 NaKCl). The temperature of the bath is low and the method of heating under degasifying conditions and uniformity of distribution results in avoiding serious distortion, warping and scaling. The steel parts are rendered machinable with ordinary cutting tools, so that changes, alterations or additional machining may be performed.

The paper also points out service conditions under which nitrided steel parts do not perform satisfactorily since, due to atmospheric conditions, deterioration by chemical reactions are inevitable.

Apparently denitrided steels can again be reprocessed without in any way affecting the quality of the case. Hardness, chemical inertness and other characteristics do not seem to be impaired at all and service performance has been equally as good on renitrided parts as on original work.

INTRODUCTION

HISTORICAL—One of the most frequently encountered objections to the application of nitrided steels in die molds and parts where changes in die impression and fitting parts are more or less frequent, is the fact that ordinary annealing methods involving heating and slow cooling in gaseous atmospheres, liquid lead baths or vacuum furnaces are not successful nor practical. Temperature ranges up to 2000 degrees Fahr. do not render the nitrided case machinable with ordinary machine cutting tools. Even uniform grinding is difficult to perform after such treatment. Obviously to

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subject close fitting parts to thermal treatments at such high temperatures would cause excessive distortion and is entirely impractical for other reasons. It was my good fortune to discover quite early in the nitriding development stages, the practical method of softening nitrided steels. During a visit with G. Albert Lyon, the automobile bumper inventor, in July 1926, at Asbury Park, N. J., while discussing nitrided forming dies for his ring bumper forming machine, the consideration of probable changes and alteration of contours and curvature led to an experiment for softening with several nitrided cylindrical slugs made of aluminum-molybdenum nitriding steel. The slugs were nitrided by A. Machlet of the American Gas Furnace Co., Elizabeth, N. J. One slug was heated in the gas-heated combustion chamber of a shallow circular container salt bath furnace of special design for ring bumper heating, to 1800 degrees Fahr. while the other slug was immersed in the fused salt of 50/50 NaKCl composition held at a temperature around 1500 degrees Fahr. The piece heated in the fused salt responded nicely to the treatment and was entirely soft to the file after some time of immersion followed by slow cooling. The other piece heated in the combustion chamber for several hours at 1800 degrees Fahr. did not lose its file hardness but scaled slightly.

Experimental Work—Subsequent work with nitrided steel parts showed that softening or decomposition of the nitrides takes place at lower temperatures or near the melting or fusion point of the salt mixture. However, the surface or skin only is softened and the underlying case is not affected. At high temperature apparently a diffusion of the nitrides of the case into the denitrided surface layer takes place and further decomposition results until a very marked dilution to complete decomposition occurs.

The physical-chemical reaction of the process is probably a formation of (NCl_3) nitrogen trichloride gas by interaction of MoFeN_2 and NaKCl at the surface where intimate contact at high temperature between the fused alkaline chlorides and the nitrides exists under exclusion of other interfering gaseous elements and compounds. The speed of the migration of the nitrides of the case to the surface obviously depends upon the temperature of the steel and the bath, the higher temperature naturally favoring a shortening of time period for decomposition and dilution or softening of the nitrided case.

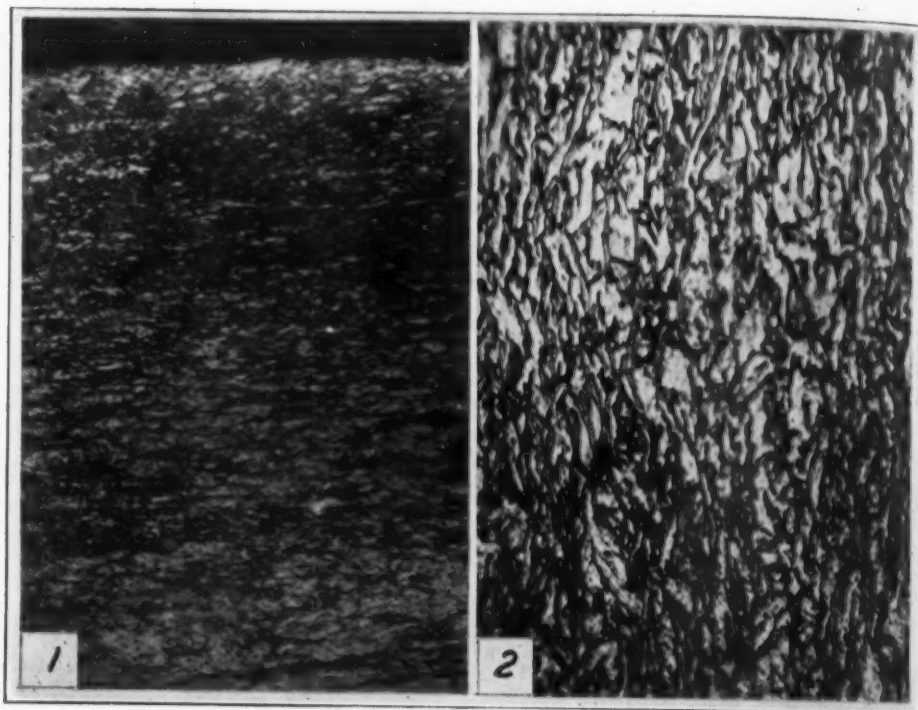


Fig. 1—Strip of Aluminum-Molybdenum Steel $\frac{3}{16}$ Inch Thick Nitrided Through Its Entire Section. $\times 125$.
Fig. 2—Same as Fig. 1. $\times 850$.

The softening of the case of nitrided steel is therefore primarily a chemical decomposition of the hardening compound and the elimination of one of its elements nitrogen in a gaseous form (NCl_3) after reactions and combining with the chloride reagent. Denitriding, therefore, cannot be classed as an annealing operation, since annealing of steel is due to a grain structure modification upon heating. Migration and diffusion of nitrides naturally occurs also inwardly so that a complete denitriding in fairly large sized cross sections cannot be expected. However, a considerable dilution of the concentration of the nitrides is producing a softening of sufficient degree to allow machining to be performed. Intensified nitride migration to the outside is evident from the photomicrographs. The chemical reactions apparently have a catalytic effect influencing the direction of diffusion toward the surface. An interesting illustration of these changes during denitriding is presented in the set of four photomicrographs. Figs. 1, 2 and 3 are sections from a strip of steel $\frac{3}{16}$ inches by $1\frac{1}{2}$ inches by 12 inches in length of aluminum-molybdenum nitriding steel which was nitrided through its entire section

to determine the physical characteristics and strength of the nitrided case. Fig. 1 is the section at 125 diameters magnification, while Fig. 2 is the same section at 850 diameters. Fig. 3 is part of this strip denitrided and shows complete softening and decomposition of the nitrides. Obviously complete decomposition is not necessary in most cases and it is practical only when dealing with thin sections. Fig. 4 is a partly denitrided piece of aluminum-molybdenum nitriding steel of greater cross section at 150 diameters magnification and shows the tendency of diffusion toward the surface. There is some diffusion inward however so that dilution rather than complete decomposition of the nitrides will be accomplished in heavier section material. Denitriding is a time-temperature reaction and its speed is directly proportional to the temperature above the fusion or melting point of the salt mixture, and since a practical speed of diffusion of nitrides requires a temperature of approximately 1500 degrees Fahr. the temperature for denitriding should be about 1500 degrees Fahr.

DENITRIDING OF NITRIDED STEEL SURFACES BY CHLORINE CONTAINING GASES

Surface denitriding by chemical decomposition and formation of a nitrogen halide with gaseous halide compounds such as chlorides, bromides, fluorides, iodides is encountered in service on nitrided valves in internal combustion engines which use ethyl bromide compounded gasoline fuel. The result is a pitted valve surface and a leaky valve. The limitation of nitrided steel parts in service where a halide gas or one of its compounds is a constituent of the atmosphere is consequently evident. Denitriding in hot dry chlorine gas would be an interesting experiment although its pitting action by chemical attack on other ingredients of the nitrided case will probably militate against its application. Mention should be made here that denitriding of nitralloy, the chromium-aluminum steels, is equally as successful in the fused KNaCl bath, in fact the removal of the nitrides by decomposition is more complete for two reasons—

1. Inward diffusion is less, due to greater sluggishness of migration in chromium alloys.
2. Nitrided cases of chromium alloy steels are generally thinner than those obtained on aluminum-molybdenum alloy steels.

The experiments made on denitriding included nitrided alumi-

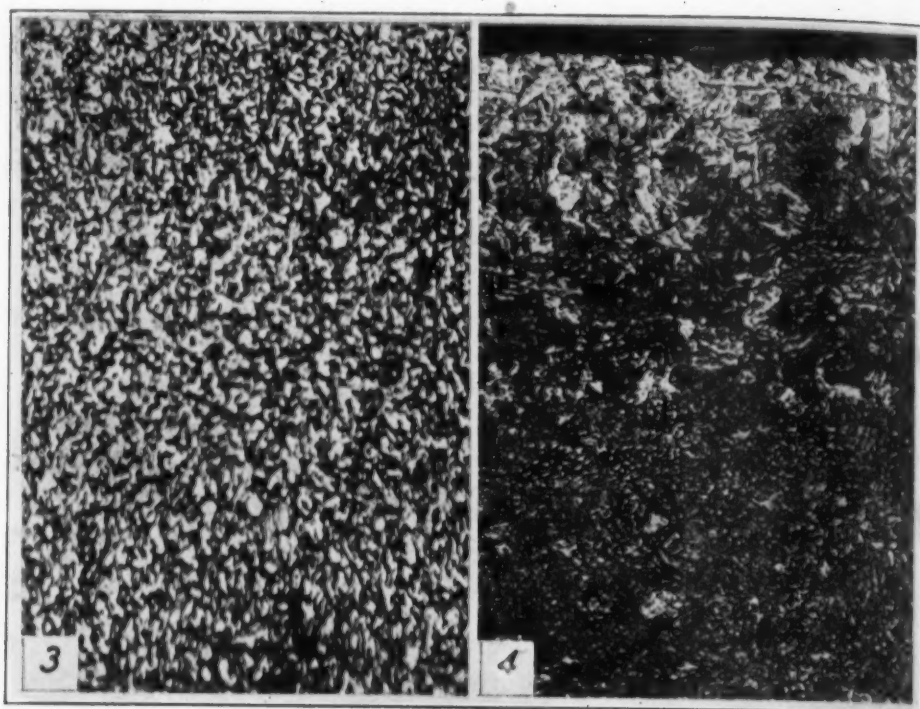


Fig. 3—Completely Denitrified Strip of Aluminum-Molybdenum Steel $\frac{1}{8}$ Inch Thick. Same Specimen Used After Nitriding as in Fig. 1. Specimen Entirely Soft. $\times 850$.

Fig. 4—Partly Denitrified Strip of Aluminum-Molybdenum Steel $\frac{1}{8}$ Inch Thick Showing Tendency of Nitrides to Diffuse Toward Surface and Center During Treatment in Fused NaKCl Salt Bath. $\times 150$.

num-chromium steels although the details of the practice were worked out on molybdenum-aluminum steels, the alloy used by the Westinghouse Electric and Manufacturing Co. on nitrided parts.

THE DENITRIDING PROCESS

In actual practice the denitridding is carried out by immersing the nitrided part in the fused salt bath of large enough volume and which is at a temperature sufficiently high to keep the salt liquid on putting the part into it. The bath and piece is heated to a temperature of approximately 1450 to 1500 degrees Fahr. and is held for sufficient time to assure uniform penetration and is then cooled slowly to slightly above the freezing point and held to equalize temperature. The piece is then removed from the bath. The adhering salt film is shaken off and the piece allowed to cool in lime. For deep cases, the time period for holding at high heat should be 2 to 3 hours. Molybdenum steels of over 0.50 per cent molyb-

dendum exhibit air hardening characteristics. It is therefore essential that slow cooling be conducted. Distortion also is kept to a minimum by such procedure. A Brinell hardness below 250 can usually be obtained on denitrided parts, which hardness permits machining. Any adhering salt film must be removed by washing in boiling hot water before the softened parts reach a temperature below 200 degrees Fahr. to avoid pitting and corroding of surface by the hygroscopic salt.

RENITRIDING OF SOFTENED ALUMINUM-MOLYBDENUM STEELS

Renitriding of parts so softened has not introduced any difficulties, nor has it produced new characteristics; although this work has not been extended to the aluminum-chromium steels, so there may be a remote possibility that aluminum-chromium steels may respond differently but more favorably to reprocessing, than the original material.

SUMMARY

A summary of the pertinent and important points relating to the softening of nitrided aluminum-molybdenum steels include the following:

1. The chemical decomposition of nitrides resulting in the softening of hard nitrided steels is a time-temperature process consisting of surface decomposition of the nitrides, followed by diffusion into the nitride-free area of nitrides migrating from more centrally located areas of the case, presenting a further supply for chemical reaction with chlorides at temperatures which permit simultaneously diffusion and chemical decomposition.

2. Fused double alkaline chloride salt baths offer a practical equipment for a process of denitriding steel parts for the purpose of rendering them again machinable for alteration, changes or modifications of design of such parts.

3. Gaseous atmospheres containing chlorine gas or a halide compound at elevated temperatures such as result from combustion of ethyl bromide charged gasoline will decompose nitrided part with which it comes in contact and causes pitting and serious defection.

4. Denitrided parts can again be renitrided without apparent loss in quality from the originally nitrided steel.

5. Complete denitriding is practical only on parts of thin

cross section, since inward diffusion occurs on heavier parts, with consequent dilution of nitride concentration and softening of the case to allow re-machining, rendering further chemical softening unnecessary.

CONCLUSION

In concluding, the writer wishes to point out that the information is of tremendous value to the nitriding industry as well as the die casting industry, since it removes the only obstacle to employ nitriding steels for die molds, namely the much heralded inability to soften the die for changes appearing necessary after castings have been made and which are found to require alteration in gating or modifications of design for satisfactory service.

DISCUSSION

V. O. HOMERBERG¹: I know that those of us who are interested in the nitriding process will appreciate Mr. Merten's contribution. Articles to be nitrided will not distort to any appreciable extent provided all internal strains are removed before their subjection to the action of the ammonia gas. There are, however, users of the nitriding process who do not observe this precaution with the result that the treated articles are distorted to such an extent that they are unfit for use. It is obvious that the application of any method whereby the nitride case can be rendered sufficiently soft for machining is of paramount importance. Two possible methods for accomplishing this result include a suitable heat treatment and the decomposition of the nitride. The use of heat treatment fails to give a hardness equivalent to less than about 450-500 Brinell. Obviously such a surface hardness cannot be machined except with great difficulty. Since Mr. Merten obtains low hardness values his results must be obtained by the decomposition of the nitride. His process makes it possible to straighten and to heat treat the articles after the decomposition of the nitride and then to re-nitride. I wish to congratulate Mr. Merten not only in this very important accomplishment, but also in the simplicity of his method.

A. B. KINZEL²: There seems to be no need to further emphasize the importance of this. Mr. Merten certainly is to be congratulated. It is a very fine piece of work. What I would like to know is, during the diffusion process, what is the approximate diffusion inwards and outwards.

GLEN COLEY³: I would like to ask Mr. Merten if there would be any effect on a nitrided piston with the car burning ethyl gasoline.

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²Member A.S.S.T., staff of Union Carbide and Carbon Research Labs., Long Island City, N. Y.

³Member A.S.S.T., power sales department, Detroit Edison Co., Detroit.

V. O. HOMERBERG: I would like to ask Mr. Merten what effect the decomposition of the nitride has upon the final dimensions of the part.

O. W. ELLIS¹: I should like to ask what direct evidence Mr. Merten has of the formation of this gas when the combination with chlorine takes place. There is, of course, considerable indirect evidence, but I would like to know if he has any direct evidence at all.

Author's Closure

When I had the photomicrograph taken the manner in which the diffusion of the nitrides took place surprised me to a very great extent. While migration does occur towards the center the greater percentage migrated to the surface, probably because of a very favorable condition of the grain structure. While I have no direct tests on physical properties, such as tensile strength, the renitrided parts, which were principally die mold parts, did, if anything, show better performance than the original ones. This was probably due to the improved grain structure plus a certain amount of refinement that had taken place by heating at 1500 degrees Fahr. in fused salt.

With regard to piston rings, I would say that while the reaction may probably not be as intense as it would be at higher temperatures, I certainly do think that a chemical activity of halides found in gaseous mixture does produce pitting. It may be slow, but it certainly does occur. In fact, I suspect that ordinary room temperature will be sufficient to bring about a decomposition of nitrides.

Unfortunately, we have not made any measurements of different physical dimensions of the materials that were put through the renitriding process, we did not find a growth differing from that of the originally nitrided material. The fitting parts of a die mold are never so close as to in any way militate against heating and cooling in a salt bath, and the probable change of 0.001 of an inch which occurs during the renitriding due to the formation of the nitrides.

Dr. Ellis' question came to me quite early in the work. For a long time I sought for a sound reason for making that statement. I finally came across the fact that the only way to produce nitrogen chloride is in that manner. It has been demonstrated to occur with all halides. Nitrogen trichloride gas does form in this manner and at the temperatures of the fused chloride salt bath.

¹Member A.S.S.T., director of metallurgical research, Ontario Research Foundation, Toronto, Canada.

A STUDY OF THE QUENCHING OF STEELS

By H. J. FRENCH

Abstract

This paper is based quite largely upon researches carried out by the author and some of his former associates at the U. S. Bureau of Standards, and its preparation was undertaken in response to requests for a coordinated summary of the several phases of the original work which was reported at intervals in separate papers. However some new data have been added.

Part One comprises a description of test methods, a discussion of the characteristics of cooling curves obtained in different coolants, and a summary of the effects of size and shape of sample upon the cooling of steels.

Consideration is given to both center and surface cooling in different coolants, and the data for center cooling are summarized both graphically and in equations which permit the computation of center cooling curves in different media for various sizes and shapes of steel.

Chapter I

INTRODUCTION—METHODS AND EQUIPMENT FOR OBTAINING COOLING CURVES

1. INTRODUCTION

THE importance of heat treatment and the widespread application of many alloy steels are largely due to the ability to vary their hardnesses, and concomitant properties, over wide limits by varying the manner of cooling from high temperatures. Therefore, studies of coolants, and of their effects upon different steels, are of practical interest as well as of fundamental importance.

This paper is based quite largely upon researches carried out by the author and some of his former associates at the U. S. Bureau of Standards during a period of 6 years. Its preparation was undertaken in response to requests for a coordinated summary of the several phases of the original work which was reported at intervals

The author, H. J. French, member of the society, is metallurgist, Development and Research Department of the International Nickel Co., Inc., Bayonne, N. J.

in separate papers. While a rearrangement of the data has been made, a large part of the descriptive matter in these papers is reproduced with only minor modifications and the author acknowledges his indebtedness to his former associates, and in particular to Messrs. O. Z. Klopsch, T. E. Hamill and G. S. Cook, for their contributions as outlined in the original papers^{1, 2, 3, 4, 5}. However, some previously unpublished data have been added and there has been amplification of some portions of the text especially as regards the practical application of the results of the experiments.

It is known that the properties of steels depend upon (1) their chemical composition, as now ordinarily determined, (2) other variables of manufacture, which cannot all be so readily defined and which are not always understood but which may be reflected in structural differences in special tests such as the McQuaid-Ehn carburizing test, (3) the temperature from which the steel is cooled, and (4) the manner of cooling.

Studies were made of each of these variables but item 4 received the most attention since one of the principal objects of the work was to make a study of coolants for heat treatment.

Variations in initial temperature of cooling (item 3) modify the cooling rates obtained in given media but sometimes they exert a more pronounced influence upon the properties of steels through changes in the temperatures at which the transformations take place.

However, the manner of cooling depends directly upon a large number of other variables. These include the composition of the coolant, its temperature and the manner in which it comes in contact with the heated metal, the size and shape of the article, the properties of the metal being cooled including the characteristics of its oxides (scale), the manner of preparation of the articles (machining and heating prior to hardening) etc. These and other variables encountered in the practical application of coolants in heat treatment

¹H. J. French and O. Z. Klopsch, "Quenching Diagrams for Carbon Steels in Relation to Some Quenching Media for Heat Treatment," *TRANSACTIONS, American Society for Steel Treating*, Vol. 3, 1924, p. 251.

²H. J. French and O. Z. Klopsch, "Initial Temperature and Mass Effects in Quenching," *Technologic Paper of the Bureau of Standards*, No. 295; *TRANSACTIONS, American Society for Steel Treating*, Vol. 9, 1926, p. 33.

³H. J. French and O. Z. Klopsch, "Characteristics of Quenching Curves," *Technologic Paper of the Bureau of Standards*, No. 313.

⁴H. J. French, G. S. Cook and T. E. Hamill, "Surface Cooling of Steels in Quenching," *TRANSACTIONS, American Society for Steel Treating*, Vol. 15, 1929, p. 217.

⁵H. J. French and T. E. Hamill, "Hot Aqueous Solutions for the Quenching of Steels," *TRANSACTIONS, American Society for Steel Treating*, Vol. 16, 1929, p. 711.

were studied in the experiments and form the basis of the succeeding discussions.

2. METHODS AND SPECIAL EQUIPMENT FOR OBTAINING THE COOLING CURVES

Perhaps the simplest method of studying coolants for heat treatment is to apply them to steel samples and examine the structures and properties produced. This method has been used widely and if the conditions of the experiments are suitably chosen the results obtained will be directly applicable to the solution of practical problems. However, such procedure shows only the results of the cooling processes and does not show the means by which the results were produced.

The procurement of cooling curves comprises a second useful method of study. While this may develop the outstanding characteristics of different coolants the data procured cannot readily be interpreted in all cases in terms of the properties of steels and the experimental difficulties encountered in studying rapid coolants often makes confirmatory data from other test methods desirable.

A more complete picture is obtained by a correlation of the cooling characteristics of different media (cooling curves) with the results produced in steels. Such a correlation is important in arriving at a more complete understanding of the characteristics of different coolants and of their effects upon steels and is the basis of the experimental work described in this paper.

The determination of the manner of cooling is relatively simple only when the rates of temperature change are low. Few methods of measurement can be applied successfully to the rapid cooling encountered in water and the aqueous solutions widely used in the quenching of steels. Also, with many of the customary cooling liquids, other difficulties are encountered in securing accurate and useful data as will become evident in the discussion of the experiments.

a. *The "String" Galvanometer and Quenching Equipment*

The cooling curves reproduced in this paper were all obtained with an Einthoven "string galvanometer" and thermocouples, suitably mounted on steel specimens. The galvanometer consisted of a tungsten wire ("string") about 0.0003 inch in diameter, suspended in a strong magnetic field.

When such a wire is connected to a source of electromotive force, (for example, a thermocouple), a deflection is obtained which is proportional to the current in the string circuit; if the magnetic field and the resistance of the string circuit remain constant, deflections of the string, (if not too large), are proportional

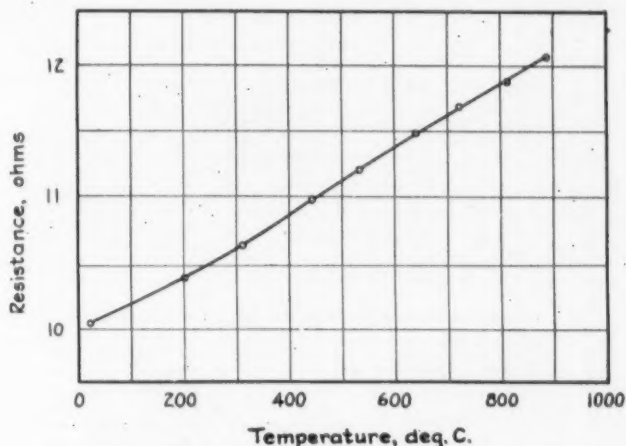


Fig. 1—Change in Resistance of Thermocouple (with Copper Leads) during a Heating or Cooling Cycle with the Equipment Described.

These Values were Used in Determining Errors in Calibration of the Apparatus which would Result from Neglect of the Change in Resistance of the Thermocouple.

to the electromotive force and may be readily converted into temperature equivalents. With the equipment used a change of about 9 millivolts [approximately 950 degrees Cent. (1740 degrees Fahr.) with platinum, platinum-rhodium thermocouples], was equivalent to about 0.0025 inch maximum deflection of the string. Actually the resistance of the string circuit changed slightly during quenching, due to the cooling of varying lengths of heated thermocouple wires, but it was found that variations from this source in the proportionality between string deflections and electromotive force were within the experimental error and, therefore, could be neglected. (See Figs. 1 and 2.)

With a suitable source of light (arc lamp) and optical equipment, the image of the string was projected, at about 500 diameters, upon a moving photographic film or paper and a continuous record of temperature so obtained. Time intervals were recorded by interrupting the beam of light by means of a slotted disk rotated at constant speed through the use of a synchronous motor and tuning fork,

Typical curves obtained with the described apparatus are reproduced in Fig. 3.

The quenching of small samples, having diameters less than about $2\frac{3}{4}$ inches, was done in the special equipment shown in Fig. 4. The specimen S with thermocouple (T) in place and mounted on a

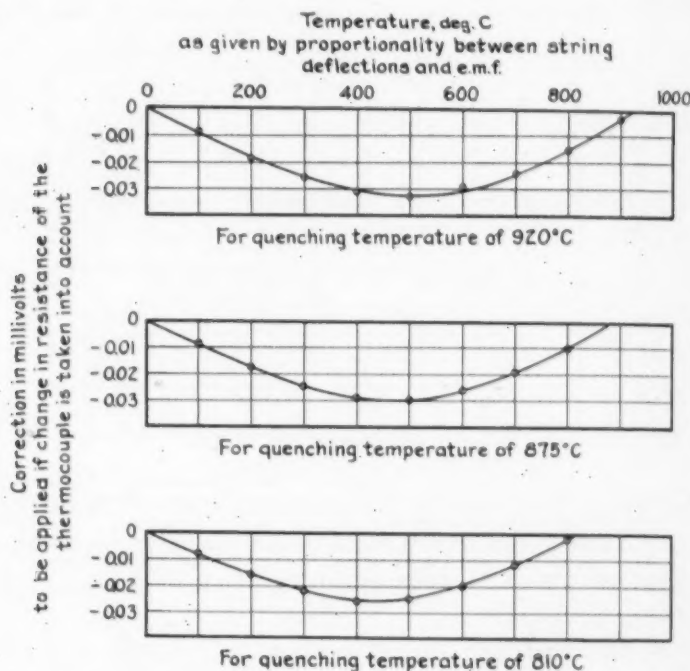


Fig. 2—Corrections to be applied when Using Various Quenching Temperatures to the Proportionality between String Deflections and emf. as a Result of Resistance Changes in the Thermocouple Circuit During Quenching.

Note that the Maximum Error Introduced by Neglect of these Changes is about 0.03 mv or 3 Degrees Cent. with the Platinum Thermocouples Used. Values were Calculated from Data given in Fig. 1 and the Resistance of the "String" which was Equal to 105.4 ohms.

carriage (C), which likewise carried an icebox for constant cold-junction temperatures of the thermocouple, was inserted into the heating unit (H). After the desired center temperature was reached and time allowed for equalization the sample was dropped by means of the lowering cord (L) into the quenching solution (Q).

Control of coolant circulation was had by mounting the quenching tank on a disk (D), which could be rotated at constant speed by motor (M) and by placing these upon a movable platform (P). Different rates of motion were obtained by varying the distance of the sample from the axis of rotation of the cylindrical quenching tank,

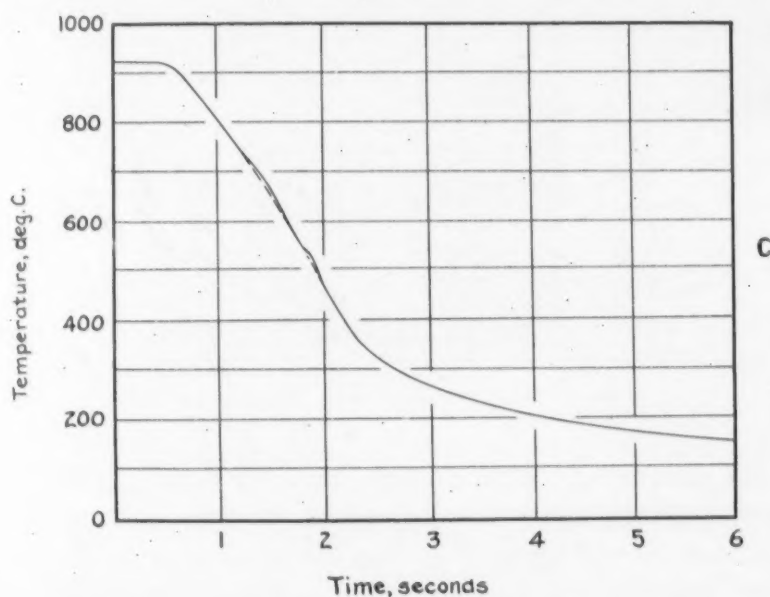
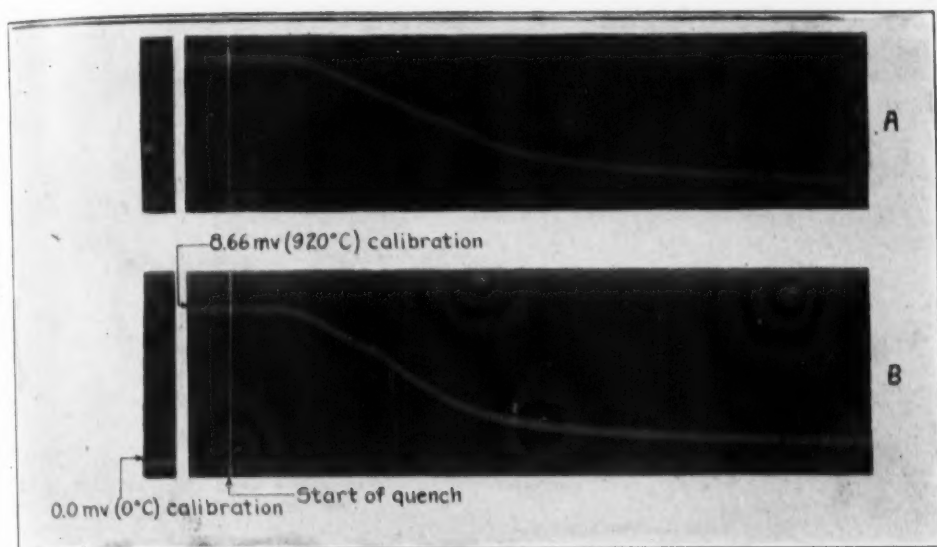


Fig. 3—Photographic Records and a Re-plotted Time-temperature Cooling Curve Obtained with the "String Galvanometer."

The Wide Band Projected on the Film is the Result of High Magnification of the "String" image; only the Upper Edge of this is Used in Calibration and Measurement of Temperatures. The Lowest Curve "C" has been Re-plotted to the Same Time Scale but an Expanded Temperature Ordinate in Accordance with the Method Used in a Majority of the Experiments. The Results shown were Obtained at the Center of $\frac{1}{2}$ -inch Diameter Cylinders Prepared from Steels Containing 0.20 to 0.25 Per Cent Carbon. "B" and "C" were Quenched from 920 Degrees Cent.; into a Motionless 5 Per Cent Sodium Hydroxide Solution at 21 Degrees Cent.; "A" was Quenched from 950 Degrees Cent. into the same Solution Flowing at 1 foot per second.

Reproduction of Photographic Records are $\frac{1}{8}$ to $\frac{1}{2}$ Original Size and do not Show the Heat Effects as Clearly as do the Original Records.

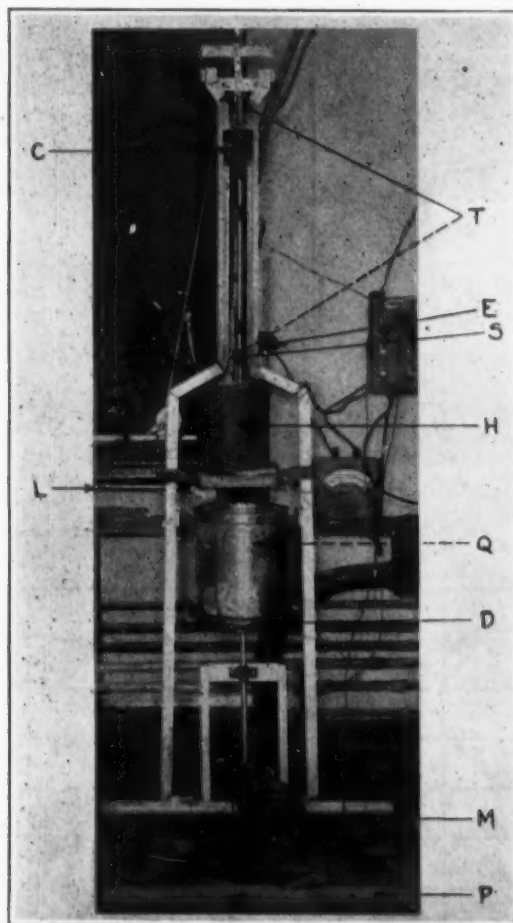


Fig. 4—Quenching Equipment Used for Small Steel Samples.

by varying the rate of rotation of the tank, or both. In the case of "still quenching" the tank was not moved.

The start of the quenching was considered to be the time at which the specimen was half immersed in the quenching bath and a record of this was made on the film by allowing carriage (C) to break the circuit (E) of an electromagnet, thus releasing an arm so placed that in falling it momentarily cut out the beam of light used to project the string image into the camera. (Refer to Fig. 3.) A photograph of the completely assembled apparatus is reproduced in Fig. 5.

The quenching of large specimens was done in a similar manner but without the special quenching device shown in Fig. 4. The

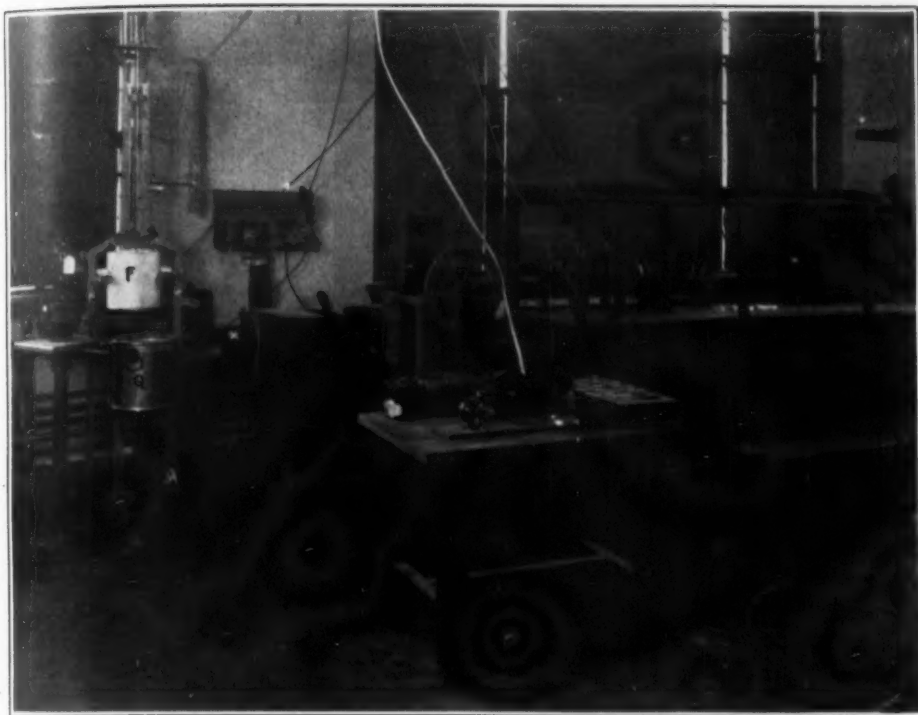


Fig. 5—Photograph Showing Assembled Equipment Used in the Tests. F = Furnace for Heating Small Specimens; Q = Bath for Quenching Small Specimens; S = Specimen; M = Motors for Rotating the Quenching Tank or Stirring Coolant; C = Camera for Recording Results; G = String Galvanometer.

samples were mounted on rods or tubes for easy handling, immersed by hand or crane in the coolant and the rotary coolant circulation in the small tank of Fig. 4 simulated by movement of the specimen in the bath.

Table I
Steels From Which the Specimens Were Prepared for Determination of the Cooling Curves

Specimen Sizes	Chemical Composition, per cent				
	C	Mn	P	S	Cr
	For Surface Temperature				
1/2" to 2 1/2" spheres ¹	1.00/1.15	0.20/0.50	<0.035	< .035	1.25/1.75
1/2" cylinders .....	.96	.28	.016	.028	
4 1/4" to 7 1/2" spheres ¹ .....	.60/ .80	0.90/1.20	<0.05	<0.05	
11" spheres and above	0.19				
	For Center Temperatures				
1/2" to 2" cylinders	0.89	0.33	0.014	0.035	
1/4" to 2 7/8" spheres	0.98				1.63
4 1/4" spheres and above	0.19				
3/8"-2" plates ¹	0.85/1.15	0.20/0.50	<0.035	<0.035	

¹Individual specimens were analyzed and the results were within the limits given in the ranges above.

Table II
Some Properties of the Principal Coolants Studied

Quenching Medium	Specific Gravity at 15 Deg. Cent.	Flash Point Deg. Cent.	Fire Point Deg. Cent.	Boiling Point Determinations			Parts per Million of Solids
				Initial Boiling Point Deg. Cent.	Final Boiling Point ¹ Deg. Cent.	Final Vapor Temperature Deg. Cent.	
A. Aqueous solutions							
Washington, D. C. city water	.....	....	...	...	...	...	132
Concentrated sulphuric acid ¹	1.840	...	...	...	...	...	...
10% sulphuric acid (by vol) ²	1.069	...	...	...	...	...	...
20% sulphuric acid (by vol) ²	1.143	...	...	...	...	...	...
10% sodium chloride (brine) (by wgt. ³)	1.073	...	...	...	...	...	...
5% sodium hydroxide (by wgt.) ⁴	1.058	...	...	...	...	...	...
11.5% sodium hydroxide (by wgt.) ⁴	1.130	...	...	...	...	...	...
16.5% sodium hydroxide (by wgt.) ⁴	1.186	...	...	...	...	...	...
B. Oils							
Prepared No. 1	0.862	182	207	380	376	352	...
Cotton seed	0.915	321	362	402	360	300	...
Sperm	0.882	260	310	390	360	300	...
Neatsfoot	0.919	249	326	400	370	320	...
Prepared No. 2	0.874	190	212	375	375	345	...
Machine	0.909	207	243	395	395	355	...

¹95% H₂SO₄.

²Prepared with c. p. concentrated (95%) sulphuric acid listed above.

³Prepared with crude commercial sodium chloride.

⁴Prepared with c. p. sodium hydroxide sticks.

⁵This is the equilibrium boiling temperature of the liquid as determined in a reflex flask under atmospheric pressure.

b. The Steel Specimens

It would have been desirable to have made all of the test specimens from one melt of steel except in those cases where differences in steel composition were being studied but it was not practicable to do so since the tests were extended gradually over a period of years and the requirements could not be forecast accurately in the preliminary stages of the investigation. However, it will become evident later that the differences existing in the composition of the different specimens, as outlined in Table I, did not appreciably alter the cooling curves except for the heat effects of transformations which were eliminated in most of the comparisons and therefore do not invalidate the conclusions drawn.

c. The Coolants

A variety of coolants were used in the experiments but the majority of the work was done with water, dilute sodium hydroxide

solutions, dilute sodium chloride brines, two proprietary quenching oils and air. Table II contains a summary of some of the physical properties of the different coolants and will help to define the liquids employed.

Washington city tap water was used in the water quenching baths and in the preparation of the sodium chloride brines and sodium hydroxide solutions. The two latter solutions were made respectively, with ordinary table salt and technical sodium hydroxide containing about 96 per cent NaOH, 2 per cent Na_2CO_3 , 2 per cent NaCl and 2 per cent of moisture. The stated concentrations of these and other aqueous solutions are weight percentages and the quenching was done in freshly prepared mixtures.

Oil No. 2 which was used in a majority of the oil quenching experiments was a proprietary product, the exact composition of which is not known. Analysis indicated that it was probably a mixture of a naphthene base (mineral) oil and about 3.3 per cent fatty oil.

Oil No. 1 was another proprietary quenching oil and its selection for a few experiments was due to its reported ability to produce relatively rapid cooling at high temperatures. It consisted of a mixture of a small amount of a heavy Pennsylvania residuum oil of high flash point with a special distilled Pennsylvania stock of low flash point, the mixture having the properties given in Table II.

d. Determination of Center Cooling Curves

In determining the center cooling curves platinum, platinum-rhodium thermocouples were inserted in the specimens in the manner shown in detail in Fig. 6. This mounting and the procedure already described for quenching the samples gave consistent results providing certain precautions were observed. The most important of these were the following:

- (1) The test samples were preferably all finish machined or ground by one method so as not to change appreciably the character of the surfaces in contact with the coolant.
- (2) The smallest practicable thermocouple "bead" was used and at the same time the largest possible surface contact maintained between it and the sample. Accordingly, after welding the thermocouple wires, the "bead" was cut in half so as to have a flat surface in contact with the speci-

men instead of point contact, such as would be given by a spherical tip.

- (3) A clean metal surface was in contact with the thermocouple. If, as was ordinarily the case, a cutting fluid was

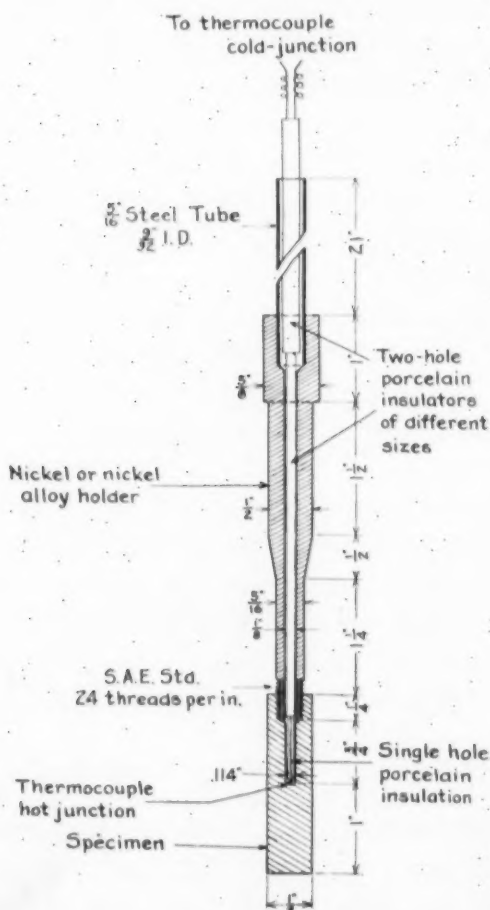


Fig. 6—Method of Mounting Thermocouple in Specimen for Obtaining Center Cooling Curves.

used in drilling the hole to the center of the specimen, all oil, small particles of metal or other foreign substances were flushed out with gasolene or other suitable cleansers.

- (4) The thermocouple was so mounted that a fairly uniform and good contact pressure was maintained with the specimen during heating and cooling. Various methods were tried with the result that the arrangement shown in Fig. 6, sometimes with an added setscrew not shown in the

- diagram, was selected. In this arrangement good contact pressure depended largely upon the proper proportions between the insulation and container tubes and careful insertion of the thermocouple into the specimen; while not an ideal arrangement, it was found to be satisfactory.
- (5) None of the quenching solution can be permitted to come in contact with the thermocouple during quenching. Thus the joints between the specimen and tubes through which the thermocouple passes (Fig. 6) must be leak-proof and so constructed that they remain intact during heating and rapid cooling.
 - (6) An accurate calibration of the thermocouple was essential. The heated ends of the platinum, platinum-rhodium wires became contaminated quite rapidly under the described conditions of test, so that it was the practice to cut off approximately half an inch of both wires after each experiment and then re-weld.

In addition to the above it was necessary to have firm contacts in the galvanometer circuit and, all leads were lead covered to avoid outside interferences.

Calibration of the assembled equipment was made before each test and was carried out substantially as follows: When the desired center temperature had been reached in the specimen as indicated by a potentiometer-indicator, the thermocouple was connected to the "string" and records of its deflection and "zero position" made on the recording film or paper (Refer to Fig. 3). The specimen was then quenched and subsequently another record made of the "zero" position of the string to avoid errors from possible movement in the camera equipment.

With this procedure the string positions were known at the chosen maximum temperature of heating and at 0 degrees Cent. (32 degrees Fahr.), and these gave a temperature calibration for the apparatus since string deflections were substantially proportional to electromotive force.

Calibration of the time marker was likewise checked before and after each experiment by actual measurement of the speed of the driving rolls for the recording film in the camera.

e. Determination of Surface Cooling Curves

The problem of securing consistent and reproducible cooling

curves at the *center* of steel bodies during quenching is not simple and for this reason it appeared to be advisable to make a statistical study of numerous experiments with specimens of different sizes and shapes, as will be reported later. The difficulties increased appreciably when attempting to study the *surface* cooling.

The transfer of heat from the metal to the coolant takes place at the surfaces of the solid body. Therefore, the observed surface cooling is directly affected by momentary and localized changes in conditions. These variations may be "smoothed out" or masked before they are transmitted to the center.

A second difficulty arises from the rapid rates of temperature change which, in certain portions of the cooling range, may reach or exceed several thousand degrees Centigrade per second in pieces 4 inches or more in diameter. Such rates of temperature change are not difficult to record with fair accuracy but a localized change in conditions, which endures for only a fraction of a second, may change the form, and shift the greater part, of the cooling curve and so give different results for supposedly similar quenching conditions. Hence, the selection of a method of test is, in itself, an important problem.

As has already been stated few methods of measurement can be adapted readily to the study of the rapid temperature changes encountered in the quenching of steels. Those most easily applied include the use of thermocouples for measuring temperatures. Both the method of attachment to the surface and the location on the test specimen may be conceived to exert a pronounced influence upon the cooling curves obtained and perhaps, also, materially affect the manner of cooling in the area where measurements are made.

Method of attaching the thermocouple to the specimen

There is no method which can be readily applied which can be said to give more than an approximate determination of surface temperatures during the quenching of steels. The attachment of thermocouples to the surface of the test specimen by any practicable method, disturbs the continuity of the surface or the underlying metal and modifies to some degree at least the conditions which can be conceived to exist in an undisturbed surface. There is, therefore, no base-line of comparison and it becomes necessary to compare the different methods of attachment of the thermocouple amongst themselves. Such comparisons will not necessarily prove that one method

gives a closer approximation to true conditions than another but should indicate which are the most promising methods.

The several methods used for attaching the thermocouple to the specimen in the preliminary tests may be grouped under two main headings, namely, (1) passage through the body of the test speci-

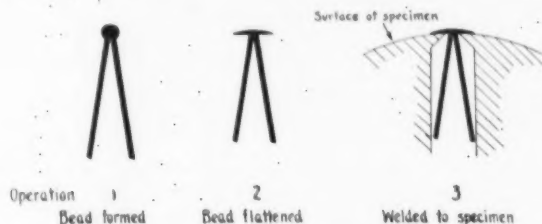


Fig. 7—Sketch Showing Method of Attachment of Thermocouple to Specimen—Method No. I.

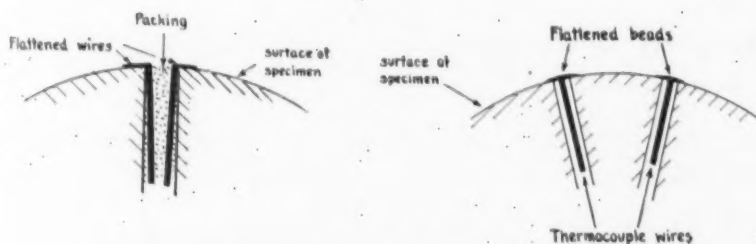


Fig. 8—Sketch Showing Method of Attachment of Thermocouple to Specimen—Method No. II. Fig. 9—Sketch Showing Method of Attachment of Thermocouple to Specimen—Method No. III.

men to the surface, and (2) attachment directly to the surface from outside the specimen. In all cases, the chromel-alumel thermocouple was attached to the surface by welding.

Method No. 1. In method No. 1, the thermocouple was first made by forming a bead on the ends of chromel-alumel wires, and the bead was then flattened. The wires were passed through a hole in the specimen and the bead welded to the steel surface over the hole, as is illustrated in Fig. 7.

Method No. 2. In this method the thermocouple wires were flattened on the ends, passed through a hole in the test specimen, laid flat on the surface, as is shown in Fig. 8, and welded individually to the steel. The hole was then packed with asbestos wool or other insulating material.

Method No. 3. In this method beads were formed separately on the ends of each thermocouple wire. The wires were passed through individual holes in the specimen, and the beads, previously

flattened, were welded over the holes to the steel surface, as is shown in Fig. 9.

Method No. 4. In the method illustrated in Fig. 10, the thermocouple wires were laid individually on the surface, from outside the test specimen, and welded to the steel.

Method No. 5. A bead was first formed on each of the ther-

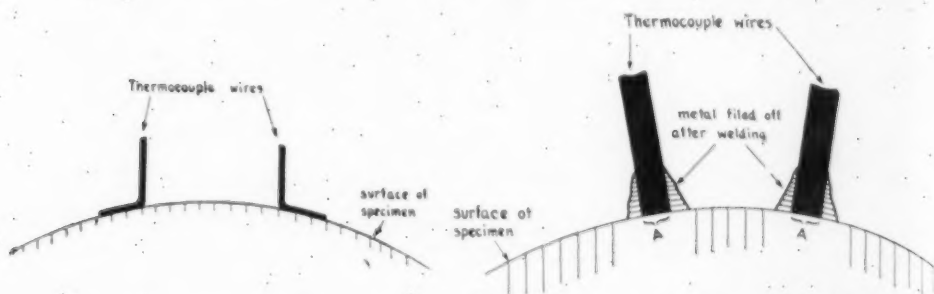


Fig. 10—Sketch Showing Method of Attachment of Thermocouple to Specimen—Method No. IV. Fig. 11—Sketch Showing Method of Attachment of Thermocouple to Specimen—Method No. V.

mocouple wires, flattened on the end and welded to the surface of the steel specimen. The excess metal was filed off subsequent to welding as is illustrated in Fig. 11.

The procedure used in welding thermocouples to the surface was as follows: A bead was made on the end of each wire by melting in an oxy-gas flame, using borax as a flux. These beads were filed flat on the ends and the wires were cleaned a short distance from the beads. Each one was then clamped between two copper blocks, one of which was connected to the secondary of a stepdown transformer (the other terminal of the secondary was connected to the vise in which the specimen was held). The end of the bead was held firmly against a freshly filed spot on the specimen while the current was made in the primary for a short time by means of a key. The voltage applied to the primary of the transformer was regulated to suit the size of wires being welded, higher voltage being required for larger wires. The best results were had without the use of any flux.

Methods 2, 3, 4 and 5 are alike in one respect. The area of the steel surface over which temperature measurements are to be made is not in contact with the coolant but is covered by a layer of the thermocouple materials. Even if this layer is thin, the temperature of the surface of the steel will presumably lag behind the temperatures of a surface in direct contact with the coolant.

One of the main objects of passing the thermocouple through

holes to the surface was to eliminate projections and approach the contour of an undisturbed surface. However, methods 1, 2, and 3 are open to the objection that the spot over which the temperature is measured is not backed up by metal as is the surface of a specimen without holes. This should be most important with method 1, in which the thermal junction between the chromel and alumel wires is directly over the hole. Furthermore, there is no ready means of de-

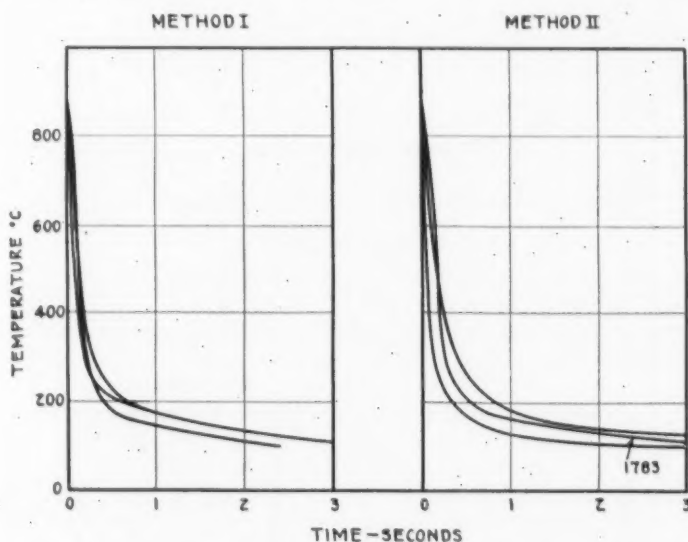


Fig. 12—Surface Cooling Curves Obtained with Methods I and II in Water Quenching. 1-Inch Spheres Quenched Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at 3 Feet Per Second. Each Curve, Except Test No. 1783, is the Average of Two or More Tests.

termining whether this thermal junction is near or well below the steel surface.

In method 2 the hole is not sealed by metal and there was generally leakage of the coolant into the packing.

Methods 4 and 5 have the disadvantage that they introduce projections from the surface of the specimen. These will tend to entrap gas and may retard the cooling. Likewise, the thermocouple leads are in contact with the coolant. Difficulties may arise from this in two ways, by conduction through the coolant and by the development of an electromotive force between the leads. Electrical conduction would tend to increase the observed speeds of cooling and counteract any retardation associated with entrapped gas. However, such increases would probably be small due to the small size of the thermocouple wires used. The effects of any electromotive force de-

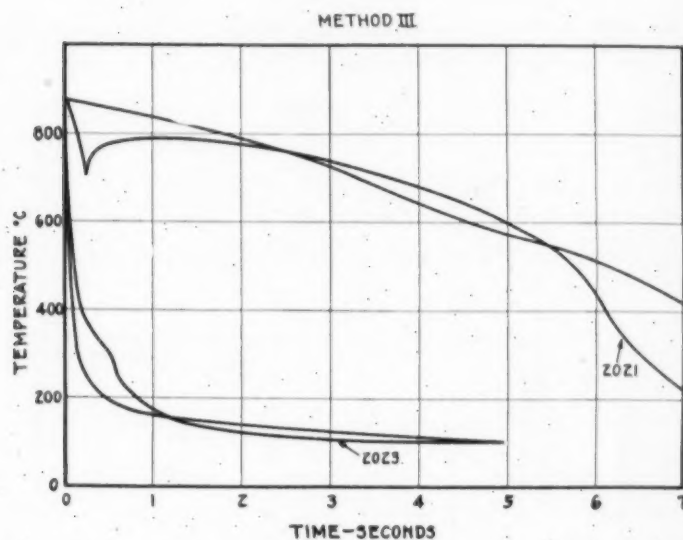


Fig. 13—Surface Cooling Curves Observed with Method III in Water Quenching. 1-Inch Spheres Quenched Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at 3 Feet Per Second. The Curves Without Test Numbers Are Averages of Two or More Tests.

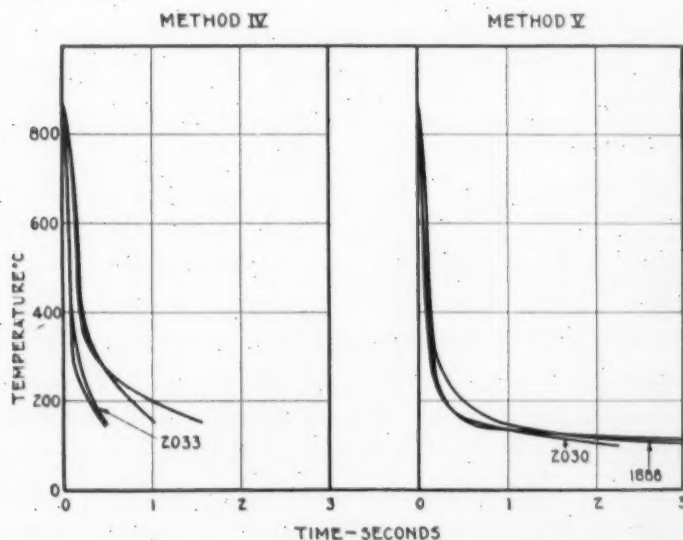


Fig. 14—Surface Cooling Curves Observed with Methods IV and V in Water Quenching. 1-Inch Spheres Quenched Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at 3 Feet Per Second. The Curves Without Test Numbers Are Averages of Two or More Tests.

veloped can probably also be neglected in the experiments under discussion as is shown by the following experiment. A specimen was prepared in the usual manner except that the thermocouple leads extended several inches below the sphere so that they protruded from the furnace. When these leads were immersed in 5 per cent sodium

hydroxide, the electromotive force indicated by a potentiometer was not affected appreciably. This gave much longer lengths of leads in contact with the coolant than obtained in the quenching experiments and would have increased such effects if they existed.

Figs. 12, 13 and 14 show surface cooling curves for 1-inch spheres quenched into water at 20 from 875 degrees Cent. (65 from

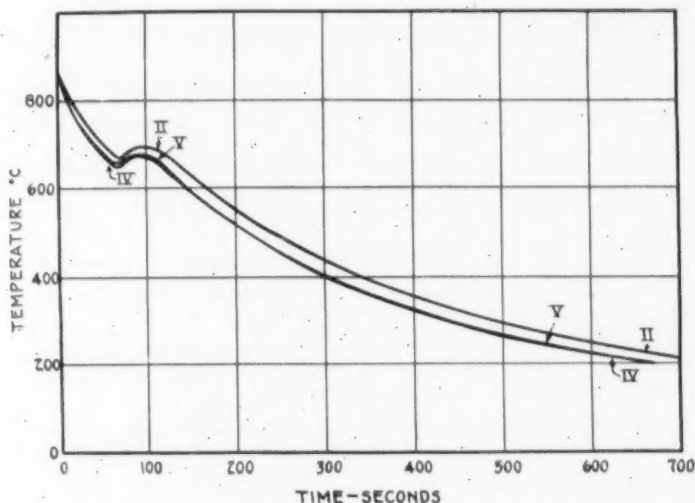


Fig. 15—Surface Cooling Curves Obtained in Still Air With Methods II, IV and V. Each Curve is the Average of Two Tests.

1605 degrees Fahr.) when using each of the five methods for attaching the thermocouple to the specimen. The most consistent results were obtained in repeated experiments with method 5. Fair consistency is shown in Fig. 12 for method 1, but much wider variations were encountered with this method in experiments with larger spheres. Method 4 gave fairly consistent results, the greatest variations being observed at the low temperatures. Erratic results were obtained with method 3.

Method 5 which gave the most consistent results is the one in which it should be least troublesome to reproduce the construction of the thermocouple mounting. The area of contact is the cross-sectional area of the wire and can be made very nearly the same each time. If the weld does not extend over the entire contact surface breakage usually results, if not while filing away excess metal, upon quenching.

As has been mentioned previously these five methods of measuring temperatures during quenching should all give a lag which

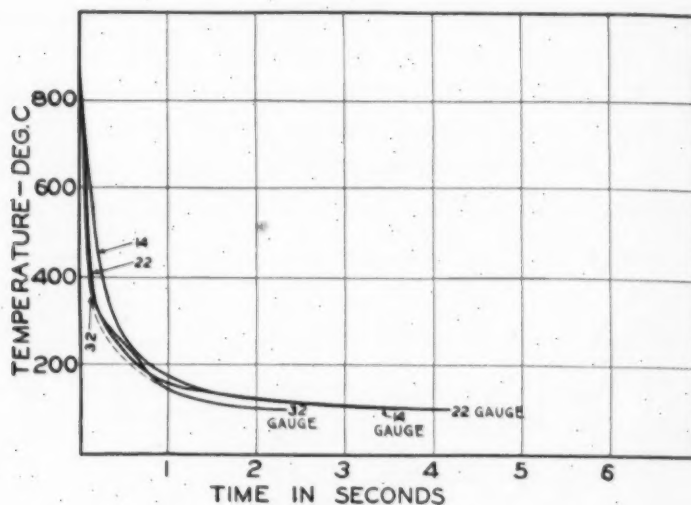


Fig. 16—Surface Cooling Curves. Obtained With Thermocouples of Different Sizes When Quenching Into Water. The Thermocouple was Attached to the Specimen by Method V. Each Curve is the Average of Two or Three Tests on a 1-Inch Sphere Quenched Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at 3 Feet Per Second.

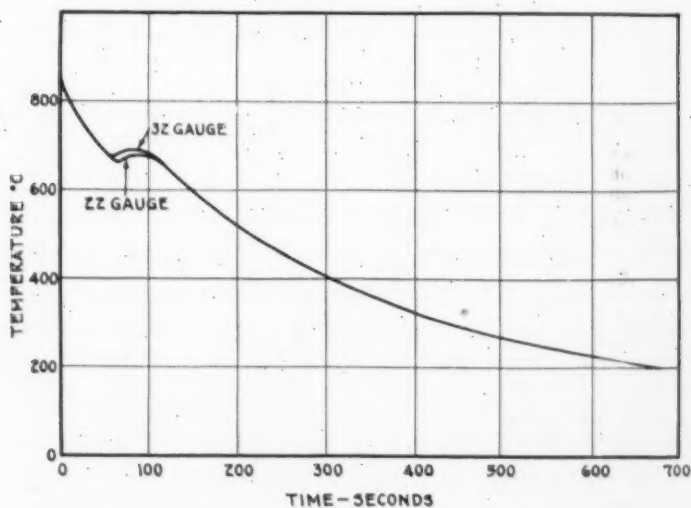


Fig. 17—Surface Cooling Curves Obtained with Thermocouples of Different Sizes When Cooling in Still Air. The Thermocouple was Attached to the Specimen by Method IV. Each Curve is the Average of Two Tests.

should be at a maximum during the early part of the quench where the temperature gradients are largest. It seems reasonable to assume that this lag is least in cases where the initial drop in indicated temperature is most abrupt. One of the curves taken by method 3 shows a somewhat more rapid temperature drop than any of the others. However, method 5 consistently gave the most rapid initial

drop in temperature of any of the methods, but when comparisons were made between the most rapid cooling curves obtained by each method the results were found to be nearly the same.

The differences encountered with different methods of attaching the thermocouple to the test specimen are reduced with slower

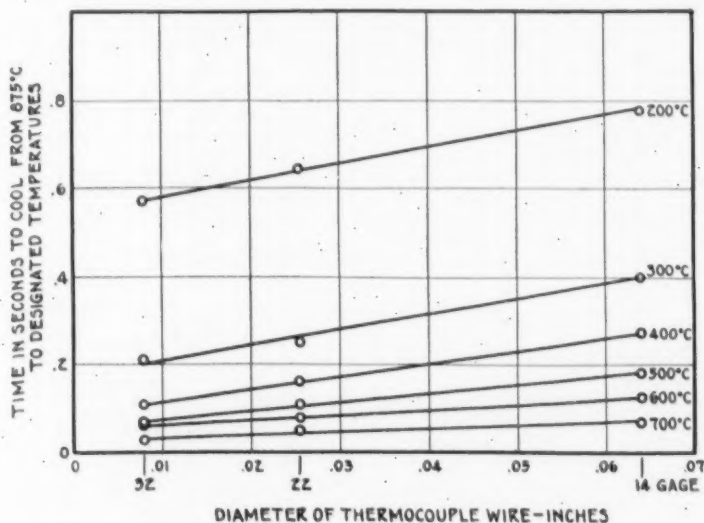


Fig. 18—Effect of Thermocouple Size on the Observed Time of Cooling from 875 Degrees Cent. (1605 Degrees Fahr.) to the Designated Temperatures When Quenching Into Water. 1-Inch Sphere Quenched Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at 3 Feet Per Second. Based on Data Given in Fig. 16.

cooling rates, as in air. Methods 4 and 5 gave practically the same air cooling curves. The cooling observed with method 2 was slow in air, just as it was relatively slow in water (Fig. 15).

Based on these experiments it seemed logical to select method 5 for rapid coolants since the lag introduced by this method of attaching the thermocouple to the surface was as small as with any of the other methods. Furthermore, it was easiest to reproduce the construction of the thermocouple in this method. With slow cooling, as in air, methods 4 or 5 may be used since they gave practically the same cooling curves.

Size of thermocouple

The experiments described indicate that the method of attaching the thermocouple to the surface may affect the observed cooling appreciably. It is probable that the observations are also affected by the size of thermocouple wire.

Cooling curves taken in water with method 5 using 14, 22 and 32 B. and S. gage thermocouples are shown in Fig. 16. Air cooling curves obtained by method 4 using 22 and 32 gage thermocouples are shown in Fig. 17.

The effect of thermocouple size upon the recorded times for the surface of a sphere to reach different temperatures when quenched

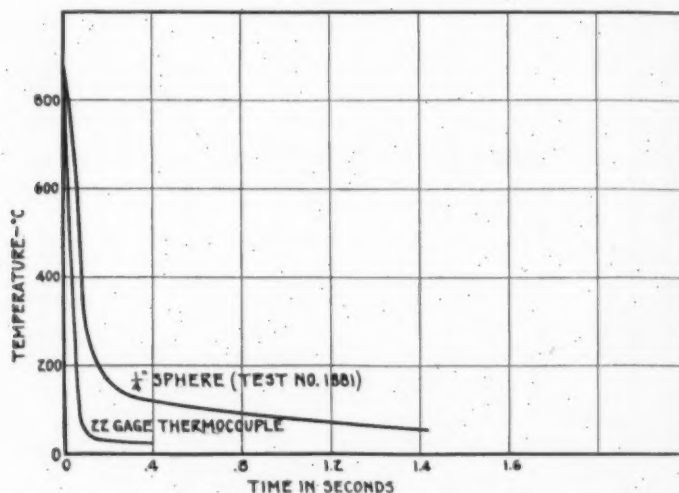


Fig. 19—Comparison of Cooling Curves for a 22 Gage Thermocouple and for the Surface of a $\frac{1}{4}$ -Inch Sphere Both Quenched Into Water at 20 Degrees Cent. (65 Degrees Fahr.); Moving at 3 Feet Per Second. Note That These Curves Are Plotted to an Expanded Time Scale.

from 875 degrees Cent. (1605 degrees Fahr.) into water is shown in Fig. 18. These times decrease generally with decrease in size of the thermocouple and within the limits of the experiments (size of thermocouple and errors), appear to be a linear function of the diameter of the thermocouple wire.

It will also be observed from Fig. 18 that the decrease in cooling time with decrease in size of thermocouple is greater for the large cooling ranges 875 to 200 or 300 degrees Cent. (1605 to 390 or 570 degrees Fahr.) than for the small cooling intervals 875 to 600 or 700 degrees Cent. (1605 to 1110 or 1290 degrees Fahr.)

Fig. 18 suggests the possibility of extrapolating the results to wires of zero diameter but this is hardly justified without extending observations to wires of much smaller diameter than 32 B and S gage. While decrease in thermocouple size should give a closer approximation to surface temperatures, practical difficulties were encountered in handling 32-gage thermocouples, and it was considered

that the use of a 22-gage wire would meet the requirements of the tests in view. In considering this selection, it should be kept in mind that there are many variables associated with the quenching process which are difficult to control and which may produce differences much larger than those resulting from a change in thermocouple size. This will become evident in subsequent discussions.

Comparison of Figs. 16 and 17 shows that the thermocouple size is less important in air cooling than in rapid cooling in water. Therefore, it is probable that the variations encountered in water quenching a 1-inch sphere (shown in Fig. 16) are larger than those which would be observed in water quenching larger spheres.

Response of galvanometer equipment

The rates of temperature change observed in the foregoing experiments were very high in portions of the cooling range. The question arises whether these rapid changes are so close to the limits of response of the thermocouple and string galvanometer equipment as to affect the observed results. A 22-gage chromel-alumel thermocouple (without a steel specimen) was quenched in water at 20 degrees Cent. (65 degrees Fahr.), to throw light on this question. The couple was made by welding the ends of the two wires together and filing away excess metal at the junction until the bead was reduced approximately to the diameter of one wire.

Fig. 19 shows that the cooling observed on the thermocouple alone was much faster than that observed on any specimen. Thus, the equipment is capable of recording higher rates of temperature change than those encountered with any of the spheres tested. The recorded cooling of the thermocouple is quite different from that of a similar couple attached to the surface of a steel sphere. Therefore, the results for the spheres cannot properly be considered to represent merely the cooling of a thermocouple suspended from a metal sample. They approach the cooling at the surface of the steel specimens.

The response of the galvanometer is another factor which imposes a limit on the cooling rates which can be determined. In the case of the described equipment, this limit is well above the rates of temperature change which must be measured. As the galvanometer was used, it had a period of about 0.01 seconds, short circuited, and it was not critically damped. It was therefore, un-

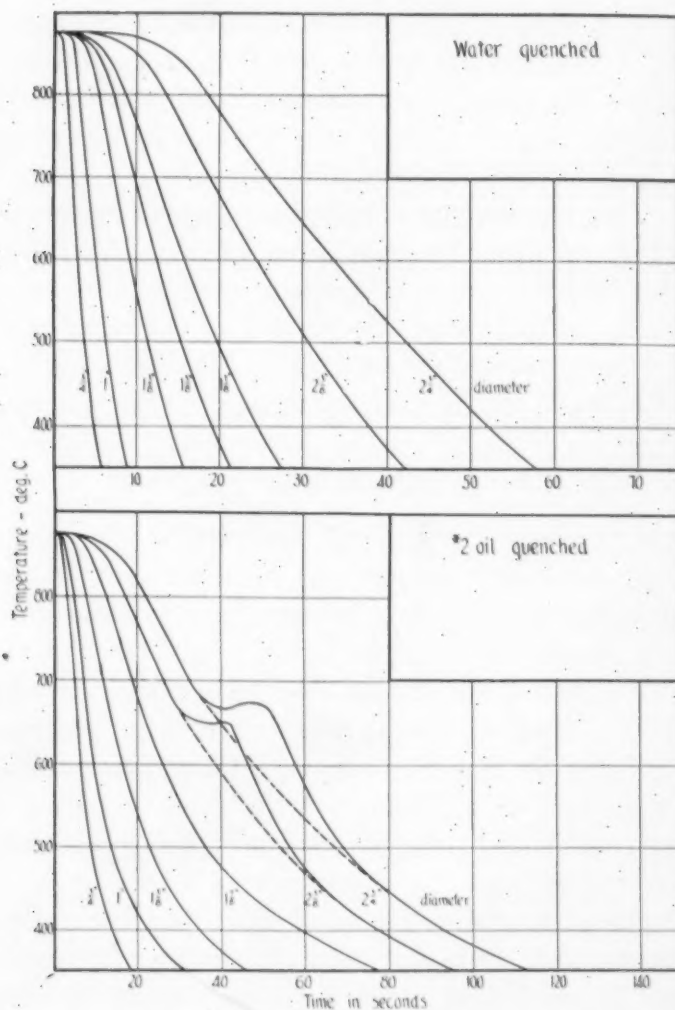


Fig. 20—Time-temperature Cooling Curves at the Center of Ball Race Steel Spheres of Different Sizes Quenched from 875 Degrees Cent. into Either Motionless Water or No. 2 Oil at 20 Degrees Cent.

necessary to attempt any correction for lag in the galvanometer as such corrections would have been beyond the accuracy of the observations.

f. General Characteristics of the Cooling Curves. At the Center of Spheres

Fig. 20 shows typical time-temperature cooling curves obtained at the center of steel spheres of different sizes, as replotted from the photographic records of time-deflection changes in the string galvanometer. The curves are all smooth and indicate that once

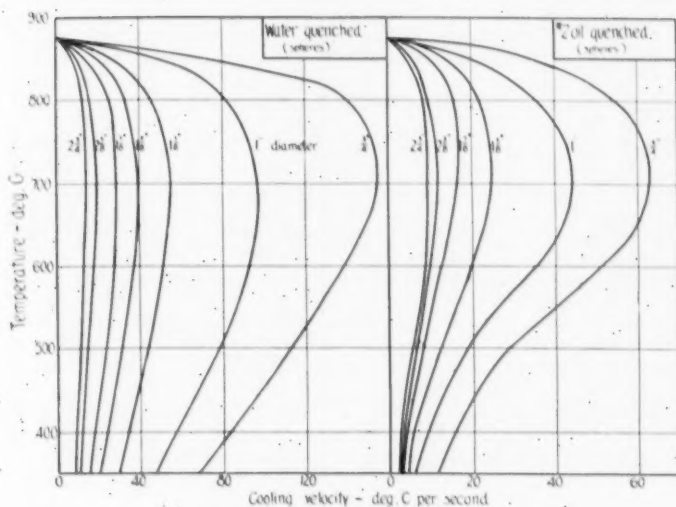


Fig. 21—Cooling Velocity-temperature Curves Taken at the Center of Ball Race Steel Spheres of Different Sizes Quenched from 875 Degrees Cent. Into Either Motionless Water or No. 2 Oil at 20 Degrees Cent.

The Transformations in the 2 3/4 and 2 3/4 Inch Diameter Spheres Quenched in Oil Have Been Disregarded in Plotting the Smooth Curves.

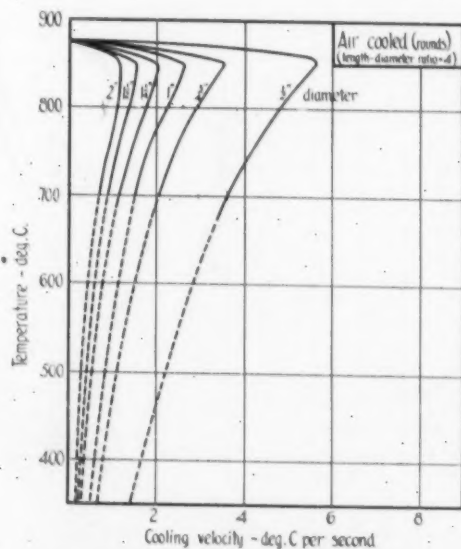


Fig. 22 — Cooling Velocity-temperature Curves Taken at the Center of 0.89 Per Cent C Steel Rounds of Different Sizes Cooled from 875 Degrees Cent. in Still Air at 22 Degrees Cent.

Dotted Lines Indicate an Extrapolation in Which the Heat Effects of the Transformations are Neglected.

cooling begins at the center it proceeds uninterruptedly except for the heat effects of transformations in the steel. When these oc-

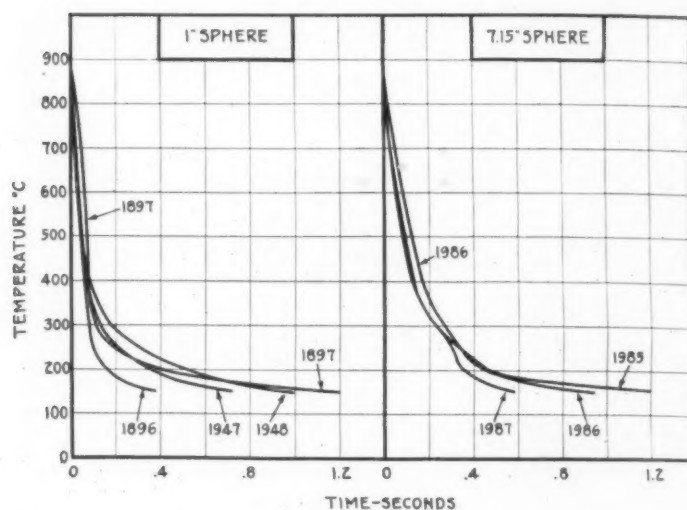


Fig. 23—Surface Cooling Curves of Spheres of Different Diameters Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into 5 Per Cent Sodium Hydroxide at 19 to 22 Degrees Cent. (65 to 70 Degrees Fahr.). Coolant Motion Approximately 3 Feet Per Second. Test Numbers Are Given in the Body of the Chart.

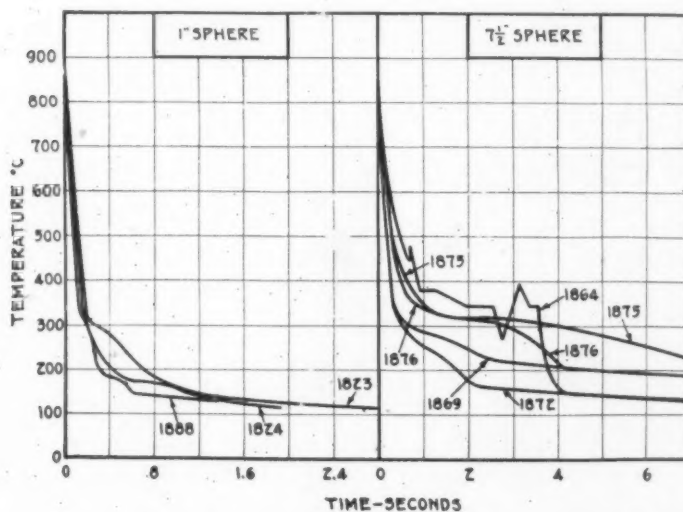


Fig. 24—Surface Cooling Curves of Spheres of Different Diameters Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water at 20 Degrees Cent. (65 Degrees Fahr.). Coolant Motion Approximately 3 Feet Per Second. Test Numbers Are Given in the Body of the Chart.

curred at low temperatures, in the neighborhood of 300 degrees Cent. (560 degrees Fahr.) the heat effects were largely suppressed and did not cause marked changes in the general trends of the curves; they will be observed readily when large, as in the oil-quenched spheres $2\frac{3}{8}$ and $2\frac{3}{4}$ inches in diameter, but in such cases the effects

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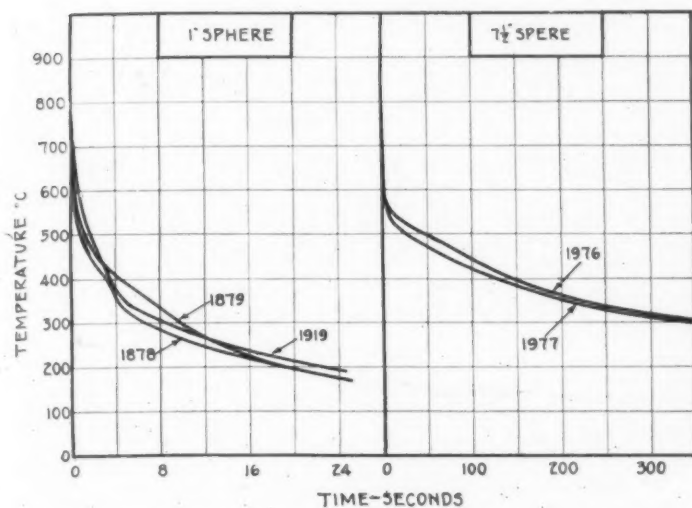


Fig. 25—Surface Cooling Curves of Spheres of Different Diameters Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into No. 2 Oil at 20 Degrees Cent. (65 Degrees Fahr.). Coolant Motion Approximately 3 Feet Per Second. Test Numbers Are Given in the Body of the Chart.

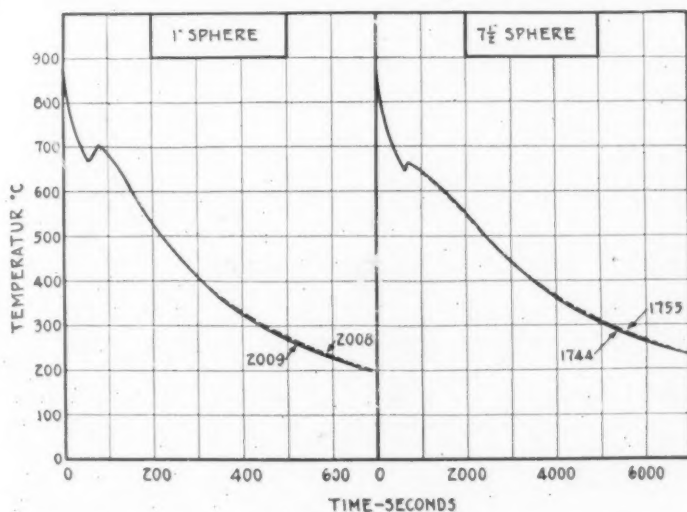


Fig. 26—Surface Cooling Curves of Spheres of Different Diameters Cooled from 875 Degrees Cent. (1605 Degrees Fahr.) in Still Air at Atmospheric Temperatures. 32 B & S Gage Thermocouple Attached to Specimens by Method IV. Test Numbers Given in the Body of the Chart.

of transformations were eliminated in the comparisons of the cooling curves in the manner shown by the dotted lines in Fig. 20.

The salient features of the center cooling curves are somewhat more clearly shown by the changes in cooling velocity with temperatures which are summarized in Figs. 21 and 22. The general

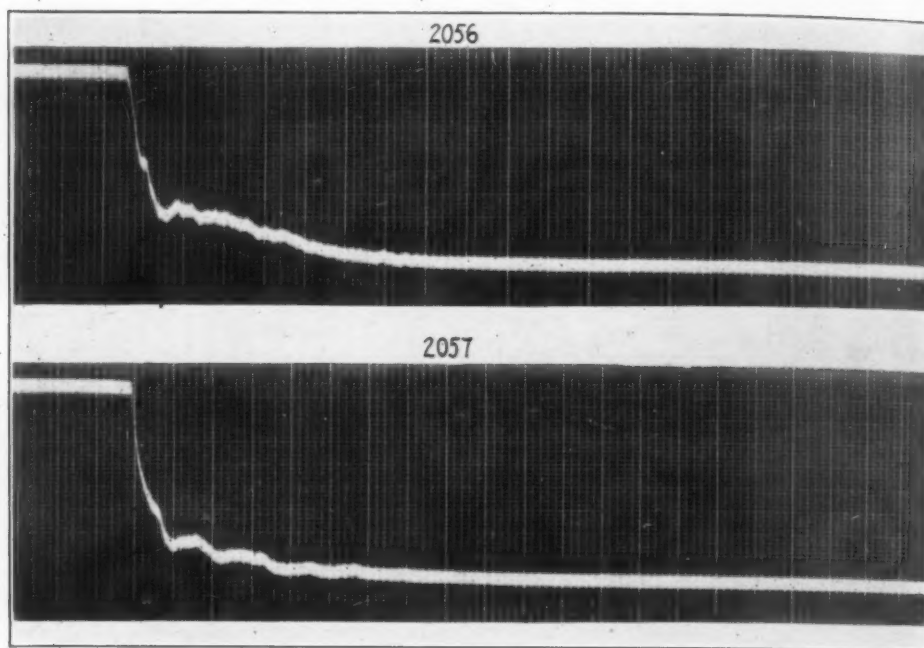


Fig. 27—Photographic Records of Surface Cooling of a $2\frac{1}{2}$ -Inch Sphere Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) Into Water at 20 Degrees Cent. (65 Degrees Fahr.), Moving at 3 Feet Per Second. Test 2056 Represents the First Quench; Test 2057 Represents the Quench After Reheating the Same Sample and Thermocouple.

character of these curves was unaffected by the diameter of the sphere but the rates of cooling decreased generally with increase in the size of the specimen.

The temperatures at which the maximum cooling velocity was obtained were lower when quenching in water or oil than in air and did not vary noticeably with the diameter of sphere. The most rapid cooling occurred at about 80-85 per cent of the quenching temperature in water and oil and very close to the initial temperature (97 per cent) in air.

At the surface of spheres

Representative cooling curves taken at the surface of spheres of different sizes quenched in different media are shown in Figs. 23 to 26 inclusive. The individual curves for each size are plotted together to give some idea of the consistency of the results.

In general, repetition of the experiments gave cooling curves which were similar for the first and last portions of the cooling range. At intermediate temperatures, around 300 to 500 degrees Cent. (570 to 930 degrees Fahr.), rather wide differences were some-

times observed. The magnitude of these variations and the intervals of both time and temperature over which they occurred increased with the diameter of the spheres. The curves also lost their smoothness in this range and showed many small fluctuations as is illustrated in Fig. 27. These fluctuations indicate an unstable condition at the areas at which the thermocouple leads were attached to the test specimen.

In replotting the cooling curves no effort was made to reproduce all the small irregularities which were observed in the photographic records (Fig. 27) since the method of recording temperatures has limitations, already discussed, which would tend to smooth out such rapid fluctuations in temperature. It is probable that the temperature of any point on the surface fluctuates over wider ranges than those shown in Fig. 27, particularly at intermediate portions of the cooling range.

These effects indicate that different points on the surface behave in different ways at least until the average temperature of the entire surface approaches the boiling point of the coolant. The fact that all the curves for any one size of sphere became nearly the same as the temperature approached the boiling point of the coolant indicates that the fluctuations and unusually high temperatures at given times reflect localized conditions. They do not necessarily indicate what happens to the surface as a whole.

In quenching large specimens in water, spots were observed to remain at "red heat" for several seconds after the steel was introduced into the coolant. This further substantiates the view that there are even more radical variations from average temperatures than are shown by any of the records obtained.

Since these small fluctuations were observed only throughout a portion of the cooling range and in some cases were almost wholly absent, they cannot justly be ascribed to electrical effects due to the action of the coolant on the thermocouple leads. Furthermore, the fluctuations were less marked, and when present, were usually restricted to smaller temperature ranges; when quenching in caustic soda with good electrical conductivity and in oil with poor conductivity than when quenching in water.

The conclusion to be drawn from the described effects is that the cooling at the surface of steel bodies immersed in liquids moving at low velocities, as in the experiments, is seldom uniform from point

to point. Evidence has also been obtained that the cooling at any particular point is not continuous but is the resultant of a large number of rapid temperature fluctuations throughout a part of the cooling range. These fluctuations were more marked when quenching in water and 5 per cent sodium hydroxide than when quenching in oil.

There is a possibility that the heat of transformations of the steel may contribute to these periods of instability but it is probable that they are largely associated with the gases which alternately become attached to and are wiped from the metal surfaces during cooling. In aqueous solutions, these gases may include steam formed at the surfaces of the hot metal, air, carbon dioxide, or other gases released from solution. Gases formed by decomposition of the coolant must also be considered in both aqueous solutions and oils.

It is generally believed that gases adhering to heated metal surfaces act as an insulator. In water quenching, a layer of steam plus gases released from solution can be conceived to form momentarily around the specimen soon after it is introduced into the bath. Until these gases are "wiped away" by the flow of the water, the cooling can be retarded. Removal of the jacket of gases would tend to increase the speed of cooling until more gases became attached to the surface to again reduce the rate of heat loss.

Under the customary conditions of quenching it is not unreasonable to assume that this cycle of steam formation and removal would occur at very rapid rates and produce the temperature fluctuations illustrated in Fig. 27.

From the viewpoint of practical heat treatment, these effects show the necessity of selecting coolants which give average cooling rates well above the critical cooling rates of the steel to be hardened. This really represents a safety factor with respect to uniformity in hardening, and may be achieved in at least two ways. The first is to vary the coolant composition, and the second is to provide adequate circulation and volume of the coolant. More detailed discussion of both of these subjects will be given later.

Chapter II

EFFECTS OF SIZE AND SHAPE OF SAMPLE ON THE COOLING IN DIFFERENT MEDIA

It is possible to gain a general idea of the effects of size and shape on the cooling of steels from the theory of heat conduction first perfected and applied by Fourier,⁶ but while some results are obtained which appear to be consistent with actual experience or tests they can not be considered quantitative, they necessitate elaborate and tedious calculations, and require various assumptions which introduce an element of doubt upon the validity of many of the conclusions which are drawn.

Comparisons by Heindlhofer⁷ of a mathematical study of the temperature changes in a hot body upon quenching and experimental cooling curves of metal cylinders quenched in water developed a number of discrepancies with the several theories on rapid cooling. The principal feature of interest in connection with the experiments to be described is that the cooling time was found to be proportional to the square of the diameter of the cylinder when quenched in the theoretically most rapid coolant in which the surface of the metal is assumed to cool instantaneously to the final temperature.

A theoretical study of the cooling of hot bodies in gases and liquids was more recently reported by Seeliger,⁸ who reviewed several available theories and emphasized the fact that they do not permit an exact solution but make possible useful deductions.

Experimental cooling curves of large sections have been obtained by a number of investigators. Fry⁹ studied large solid and hollowbored axles quenched in heavy and light oils, water, air and oil-water mixtures, but due to differences in quenching temperature and the introduction of other variables into the several experiments no general conclusions can be drawn. Law¹⁰ investigated the cooling

⁶Refer to such texts as "An introduction to the mathematical theory of heat conduction," by L. R. Ingersoll and O. J. Zobel, (1913) Ginn & Co., New York, which includes references to original articles.

⁷K. Heindlhofer, "Quenching: A mathematical study of various hypotheses on rapid cooling," *Physical Review*, Vol. 20, pp. 221-242; 1922.

⁸R. Seeliger, "Die Abkühlung heisser Körper in Gasen und Flüssigkeiten," *Physik. Zeitschr.*, Vol. 26, p. 282; 1925.

⁹L. H. Fry, "Notes on some quenching experiments," *Journal, Iron and Steel Institute*, Vol. 95, p. 119; 1917.

¹⁰E. F. Law, "Effect of mass on heat treatment," *Journal, Iron and Steel Institute*, Vol. 97, p. 333; 1918.

at the center of 18-inch cubes quenched in a water spray, a water bath, an oil and air, and likewise determined the resulting tensile properties from center to surface. The tensile strength gradients were greatest from the water bath quenching, but a maximum difference of only 1,000 lbs./in.² was found at the center in the cubes quenched in the various media (excepting air), thus indicating that the thermal properties of the steel have more to do with the center cooling in such large masses than the coolant used.

Bash¹¹ reported heating and air-cooling curves taken at different points in a 24-inch ingot, while Knight and Hansen¹² studied the cooling at a point 2 inches from the edge of an 8-inch round, 14-foot long, when quenched in cottonseed oil.

Janitzky¹³ made an experimental study of "mass effects" in heat treatment and developed equations giving the relation between the hardness produced in various sizes and shapes of carbon and alloy steels when tempered at different temperatures subsequent to hardening. He also derived useful relations by which it is possible to approximate the time required to reach any temperature in air-cooling rounds of various dimensions from different temperatures.

A feature of particular interest is that the surface per unit of volume, which in plates, rounds, and spheres is in the ratio of 1, 2, 3, when the ends and edges are neglected, is definitely related to the properties produced by quenching.

The effects of size on the tensile properties of quenched or quenched and tempered steels were studied by Zimmerschied¹⁴ and by Straub.¹⁵ While much useful information was obtained by both investigators, their results do not come within the field to be covered in this paper and will not be reviewed in detail.

¹¹F. E. Bash, "Forging temperature and rate of heating and cooling of large ingots," *Transactions, American Institute of Mining Engrs. "Pyrometry" volume*, p. 614; 1920.

¹²O. A. Knight and F. F. Hansen, "Heating, quenching, and drawing large steel forgings," *Chemical and Metallurgical Engineering*, Vol. 20, p. 590; 1919.

¹³E. Janitzky, "Hardness formulas," *Iron Trade Review*, Vol. 69, p. 1079; 1921. "Influence of mass in heat treatment," *Chemical and Metallurgical Engineering*, Vol. 25, p. 783; 1921. "Mass in the heat treatment of steel," *Iron Age*, Vol. 109, p. 658; Vol. 110, p. 788; 1922. "Influence of size on heat treating," *American Machinist*, Vol. 50, p. 1153; 1919. "A contribution to the problem of the influence of mass in heat treatment," *TRANSACTIONS, American Society for Steel Treating*, Vol. 2, p. 55; 1921. "New development on the influence of mass in heat treatment," *TRANSACTIONS, American Society for Steel Treating*, Vol. 2, p. 377; 1922. "Characteristics of air-cooling curves," *TRANSACTIONS, American Society for Steel Treating*, Vol. 3, p. 335; 1922.

¹⁴K. W. Zimmerschied, "Influence of mass in heat treatment of steel," *Iron Trade Review*, Vol. 53, p. 84; 1913.

¹⁵T. G. Straub, "Relative size in heat treatment," *Iron Age*, Vol. 104, p. 167; 1919.

One of the most interesting points in published data was given by McCance,¹⁶ who showed that the cooling velocity at the center of the high-carbon steel cylinders quenched in water by Portevin and Garvin,¹⁶ when taken at a fixed temperature of 700 degrees Cent. (1290 degrees Fahr.) was inversely proportional to some power of the diameter greater than 1 but less than 2.

I. CENTER COOLING VELOCITY, TAKEN AT 720 DEGREES CENT. (1330 DEGREES FAHR.)

The properties produced in steels are dependent upon the manner of cooling throughout the entire cooling range but the cooling rates at relatively high temperatures in the neighborhood of the equilibrium transformation temperatures must exceed certain values, irrespective of the subsequent cooling rates at much lower temperatures, if the steel is to be hardened. As has been aptly said the cooling at high temperatures provides the "will to harden" while the subsequent cooling determines the degree to which hardening takes place. These views comprise the basis for the selection of the cooling velocity at 720 degrees Cent. (1330 degrees Fahr.) for the study of the effects of size and shape on the cooling of steels.

The effect of diameter in spheres and rounds, and of thickness in plates, upon the center cooling velocity at 720 degrees Cent. (1330 degrees Fahr.) is shown in Fig. 28. The relation between the diameter or thickness and the cooling velocity is closely represented by the equation

$$V D^n = c \quad (1)$$

in which V is the cooling velocity at 720 degrees Cent. in degrees Centigrade per second, D is the stated dimension in inches (diameter for rounds and spheres and thickness for plates) and " n " and " c " are constants, the values of which are given in Table III.

Comparison of these constants shows that the numerical value of the exponent " n " is a function of the coolant while " c " is dependent upon the shape of the material as well, and, hence, upon the surface per unit of volume.

¹⁶A. McCance, "Discussion of report by A. M. Portevin and M. Garvin: The experimental investigation of the influence of the rate of cooling on the hardening of carbon steels," *Journal, Iron and steel Institute*, Vol. 99, p. 563; 1919.

Table III
Numerical Values of the Constants for Equation (1)
 [For ratio of length to diameter in rounds=4. For ratio of length to width to thickness
 in plates=4:4:1]

Conditions ⁽¹⁾	Value of—	
	$\frac{1}{n}$	$\frac{1}{m}$
Rounds quenched in motionless 5 per cent NaOH from 875° C.	1.84	61.3
Spheres quenched in motionless water from 875° C.	1.75	89.8
Rounds quenched in motionless water from 875° C.	1.75	54.1
Plates quenched in motionless water from 875° C.	1.75	27.6
Spheres quenched in motionless No. 2 oil from 875° C.	1.40	40.2
Rounds quenched in motionless No. 2 oil from 875° C.	1.40	25.0
Rounds cooled in motionless air from 875° C.	1.15	1.74

⁽¹⁾All coolants at atmospheric temperatures.

It may now be stated that in quenching:

(a) The cooling velocity, in the neighborhood of 720 degrees Cent., at the center of spheres, rounds and plates is inversely proportional to some power of the diameter (or thickness) greater than 1 and less than 2.

(b) This power varies for the different coolants; it is close to 1 for air (1.15), approaches 2 in motionless 5 per cent sodium hydroxide (1.84), and increases generally with the rapidity of the coolant.

It would at first appear that the value of the exponent " n " in equation (1) might be used to obtain a number expressing the "hardening power" of coolants as it is neither dependent upon the size nor the shape of the material. Such a derived value would, of course, be based on the assumption that the cooling velocity at 720 degrees Cent. was a quantitative measure of the martensitization or hardening produced in steels which is not exactly true. Under ordinary conditions with carbon steels it is probably a sufficiently close criterion, so that large errors would not be introduced, but there are other reasons why such a derived numerical value cannot be used. These will be discussed later.

Some useful comparisons can be developed from the data given in Fig. 28. The first has to do with the effect of the shape of the steel on the center cooling velocity taken at 720 degrees Cent. (subsequently called "cooling velocity" or "cooling rate") and may be stated as follows:

(c) For a given size, the highest cooling velocity is obtained in spheres, an intermediate rate in rounds, and the lowest in plates.

This is due to the fact that a sphere of given size has a larger surface per unit of volume by which the heat can be taken away than a round of the same diameter, and similarly a round has a larger surface per unit of volume than a plate of equal thickness.

These relations may be restated as follows:

(d) For equal cooling velocity the ratio of the diameter of spheres to the diameter of rounds and thickness of plates is as 4:3:2, provided the length of the cylinder is at least four times its diameter and the length and width are each four times the thickness of the plate.

Thus, the cooling velocity at 720 degrees Cent. (1330 degrees Fahr.) and the hardening at the center of a 1-inch sphere is the same as in a $\frac{3}{4}$ -inch round, 3 inches long, and a $\frac{1}{2}$ -inch thick plate, 2 inches long by 2 inches wide. Confirmation of this for certain sizes can be obtained directly from the experimental data tabulated in Table IV, or proof can be secured mathematically from the general relationship given by equation (1) ($VD^n=c$); at the same time such computations will show the degree of accuracy attained in the experiments from which the values of "n" and "c" were determined.

If V_s =center cooling rate, taken at 720 degrees Cent. for spheres,

V_r =center cooling rate, taken at 720 degrees Cent. for rounds,

V_t =center cooling rate, taken at 720 degrees Cent. for plates,

D_s =the diameter of the sphere,

D_r =the diameter of the round,

D_t =the thickness of the plate,

then the relation between size and cooling velocity in water quenching is given by

$$V_s D_s^{1.75} = 89.8 \text{ or } V_s = \frac{89.8}{D_s^{1.75}} \text{ for spheres} \quad (2)$$

and

$$V_r D_r^{1.75} = 54.1 \text{ or } V_r = \frac{54.1}{D_r^{1.75}} \text{ for rounds} \quad (3)$$

For equal cooling velocity in spheres and rounds V_s equals V_r

$$\text{and } \frac{89.8}{D_s^{1.75}} = \frac{54.1}{D_r^{1.75}} \text{ or}$$

$$\frac{D_s}{D_r} = \left(\frac{89.8}{54.1} \right)^{\frac{1}{1.75}} \quad (4)$$

Here the right-hand side of equation (4) represents the ratio of diameters in spheres and rounds, which will have the same cooling rate and when reduced is found to be equal to 1.33. Similar computations carried out for spheres and plates quenched in water gave

Table IV

Experimental Data Relating to Center Cooling of Rounds, Spheres and Plates
0.98 Per Cent C, 1.63 Per cent Cr, Steel Spheres Quenched from 875 Degrees Cent. into
Motionless Coolants at 20 Degrees Cent.

Size (in inches)	Surface Inches ²	Volume Inches ³	Weight Grams	Ratio surface: Volume	Cooling rate at 720° C. in ° C. per second	
					H ₂ O	Oil
3/4	1.767	0.222	25.5	8	¹ 148.5	¹ 60
1	3.142	.523	64	6	95	¹ 43.5
1 1/4	5.91	1.326	170.5	4.46	55	¹ 25.2
1 3/4	8.08	2.186	286	3.70	39	.....
1 7/8	11.05	3.450	438	3.20	28	¹ 16.6
2 3/8	17.50	6.790	894.5	2.58	20	¹ 11.4
2.77	24.10	11.110	1,425	2.10	14	9

¹Average of two values.

Table IV—Continued

0.89 Per Cent Carbon Steel Rounds Quenched from 875 Degrees Cent. into Motionless
Coolants at 20 Degrees Cent.

Size (in inches)	Surface Inches ²	Volume Inches ³	Weight Grams	Ratio surface: Volume	Cooling rate at 720° C. in ° C. per second		
					H ₂ O	No. 2 oil	Air
1/2 by 2	3.53	0.393	46.5	9	185	69	3.84
3/4 by 3	8.05	1.326	167	6	93	.37	¹ 2.37
1 by 4	14.14	3.142	396	4.5	¹ 52	23.5	1.77
1 1/4 by 5	22.09	6.135	780	3.6	¹ 37	18.5	1.36
1 1/2 by 6	31.81	10.602	1,350	3.0	¹ 27.4	.....	1.07
2 by 8	56.53	25.13	3,195	2.25	15.3	9.4	.80

Size (in inches)	Surface Inches ²	Volume Inches ³	Weight Grams	Ratio surface: Volume	Cooling rate at 720° C. in ° C. per second	
					5 per cent NaOH	
1/2 by 2	3.53	0.393	46.5	9	222	
0.744 by 2.98	7.84	1.295	161.2	6.05	105	
0.99 by 3.98	13.92	3.065	383.5	4.54	64	
1.24 by 4.96	21.77	5.980	760	3.64	37	
1.99 by 7.98	56.12	24.83	3,156	2.26	16.8	

High-Carbon Steel Plates Quenched from 875 Degrees Cent. into Water
at 20 Degrees Cent.

Size (in inches)	Surface Inches ²	Volume Inches ³	Weight Grams	Ratio surface: Volume	Cooling rate at 720° C. in ° C. per second	
					H ₂ O	
3/8 by 3/8 by 1 1/2	6.75	0.844	104.1	8	149	
1/2 by 2 by 2	12	2	253	6	97	
3/4 by 3/4 by 2 1/4	15.19	2.85	353	5.33	¹ 77	
1 by 4 by 4	48	16	2,026	3	31	
2 by 7.89 by 7.92	188.04	125	15,961	1.51	6.9	

¹Average of two values.

a ratio of diameters equal to 1.960; for spheres and rounds quenched in oil it was 1.399.

When these are compared to an assigned value of 4 to spheres the following results are obtained, which are equal, within limits of experimental error, to the stated ratios of 4: 3: 2:

	Ratio of diameters giving the same cooling rate at 720° C. in—	
	Water quench	Oil quench
Spheres	4	4
Round	3	2.86
Plates	2.04	.....

2. DATA SHOWING THAT THE CENTER COOLING TIME FOR CERTAIN INTERVALS IS INVERSELY PROPORTIONAL TO THE COOLING VELOCITY, TAKEN AT 720 DEGREES CENT.

It can be shown that the cooling velocity selected for previous comparisons is proportional to the cooling time, provided this is taken over an interval which does not begin or end at a temperature within the range of large heat effects of transformations.

In order to avoid those temperatures in which thermal effects would change both cooling rates and times and at the same time include in comparisons the cooling at both high and low temperatures, two ranges were selected, (1) the cooling time from the quenching temperature 875 to 700 degrees Cent., (1605 to 1290 degrees Fahr.) (2) the cooling time from 875 to 400 degrees Cent. (1605 to 750 degrees Fahr.)

As is shown in Fig. 29 the relation between cooling time and diameter of spheres quenched in oil or in water is closely approximated by the general equation

$$\frac{T}{D^n} = c_1 \quad (5)$$

in which T is the cooling time in seconds, D is the stated dimension in inches, and " n " and " c_1 " are constants.

The numerical value of " n " in equation (5) is the same as that in equation (1) for a given coolant. Therefore, the cooling time from either 875 to 700 degrees Cent. or 875 to 400 degrees Cent. is inversely proportional to the velocity and may be determined if the values of " c " and " c_1 " are known for the various shapes quenched in the different coolants. This may be expressed as follows:

$$T = \frac{cc_1}{V} \quad (6)$$

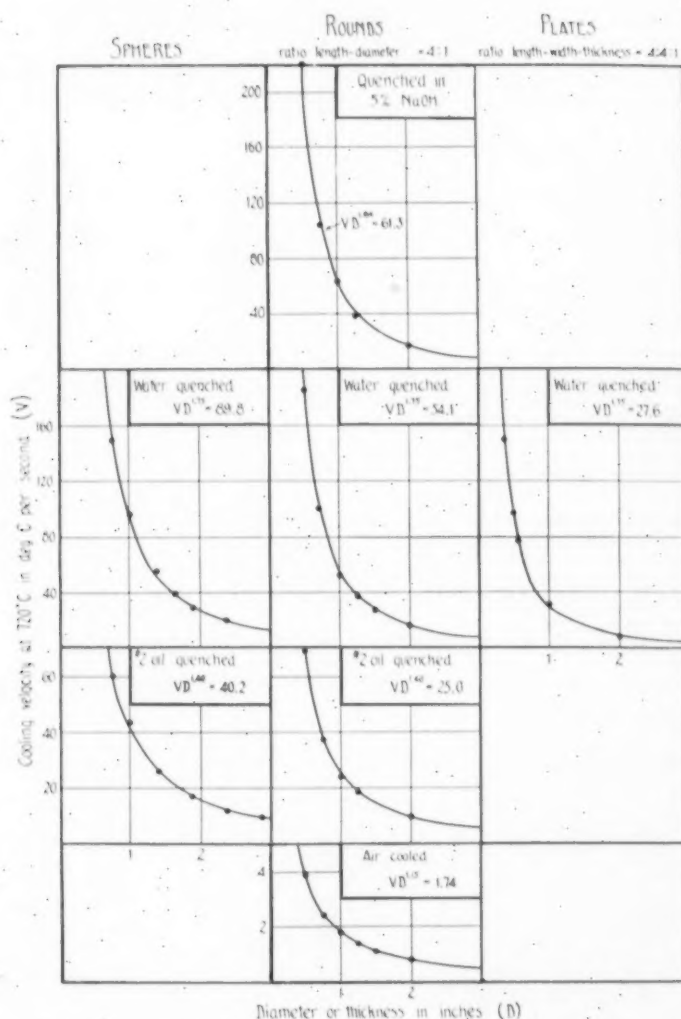


Fig. 28—Relation Between the Center Cooling Velocity, Taken at 720 Degrees Cent. and the Diameter or Thickness of High Carbon Steel Spheres, Rounds, and Plates Quenched from 875 Degrees Cent. Into Various Coolants.

in which " c_1 " is the constant of equation (5) (cooling time equation) and " c " is the constant of equation (1) (cooling velocity equation).

The numerical values of " c " and " c_1 " are dependent both upon the coolant and the shape of the material. On this account they are not here included for all shapes and coolants.

It may now be stated that—

(e) Provided the chosen interval does not begin or end at a temperature within large thermal transformations, the cooling time at the center of spheres, rounds and plates is inversely proportional to the cooling velocity taken at 720 degrees Cent. (1330 degrees Fahr.).

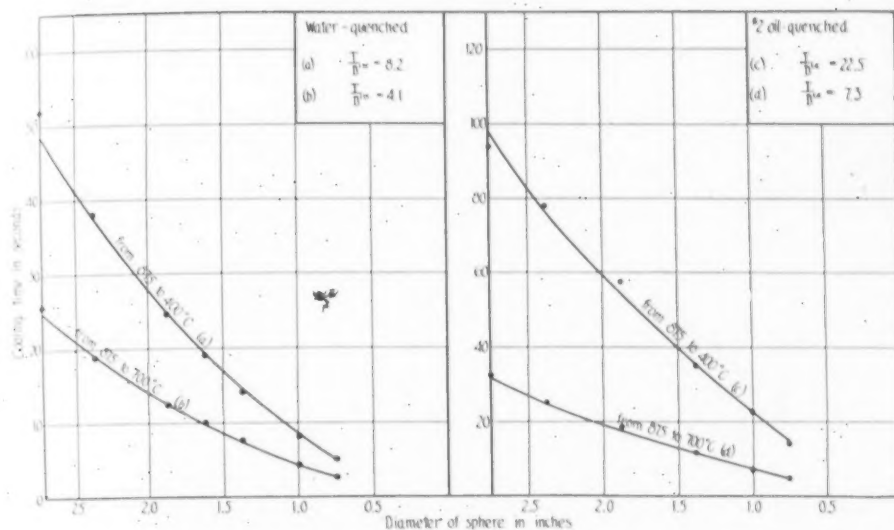


Fig. 29—Relation Between the Center Cooling Time and the Diameter of Ball Race Steel Spheres Quenched from 875 Degrees Cent. Into Either Motionless Water or No. 2 Oil at 20 Degrees Cent.

3. EFFECT OF EXPOSED SURFACE IN ROUNDS, SPHERES, AND PLATES ON THE CENTER COOLING VELOCITY, TAKEN AT 720 DEGREES CENT. (1330 DEGREES FAHR.)

The foregoing comparisons have been given for the sake of completeness and not because they are the most generally useful of those which may be secured. Aside from the necessity of having the numerical value of the constants c (equation (1)) and c_1 (equation (5)) for each set of conditions involving change in shape and coolant, the relations do not apply directly to rounds having a length-diameter ratio other than 4, and likewise can be used only for plates in which the length and width are each four times the thickness. It is therefore desirable to seek a more generally applicable relation between the cooling rate and the size and shape of material.

In cooling a heated mass heat must flow from the central zone toward the surfaces and be taken away from the body through the surfaces in contact with the coolant. Under ordinary conditions of heat treatment there is an unlimited supply of the coolant in comparison with the mass of metal to be cooled, so that the time required to take the heat away, and, hence, the rate of extraction, will be a function of the amount of heat to be removed. With a fixed initial (quenching) temperature this is proportional to the volume of a given metal. Since the exposed surface and volume are both of

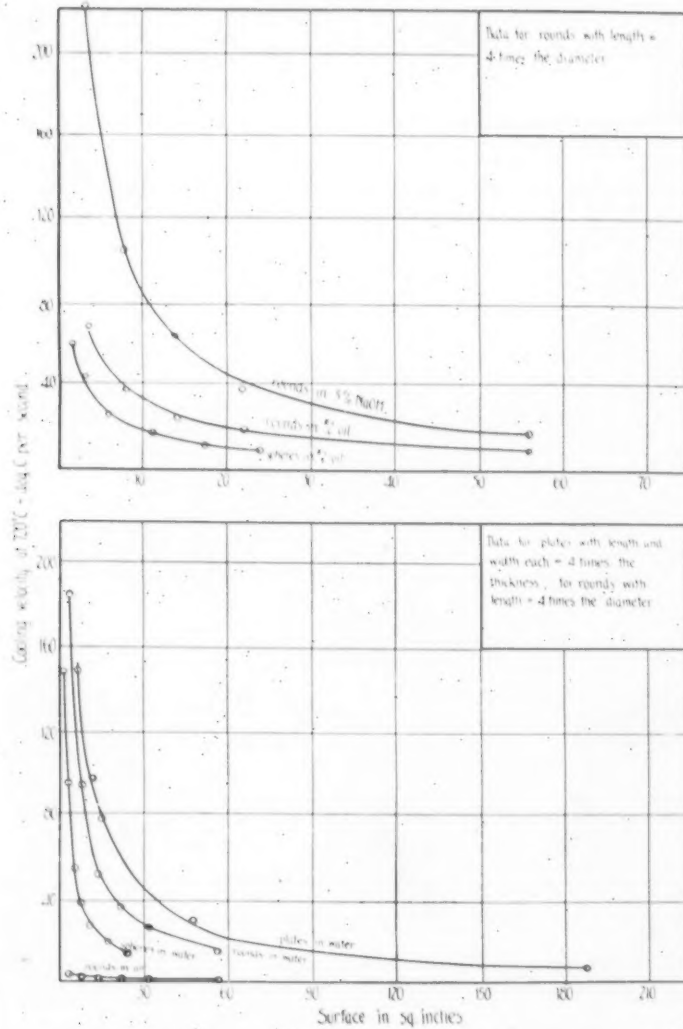


Fig. 30—Relation Between the Center Cooling Velocity, Taken at 720 Degrees Cent. and the Exposed Surface in Quenching Various Sizes and Shapes in Different Coolants from 875 Degrees Cent.

importance in determining the cooling rate in a given coolant, it is reasonable to expect that the most general relation will be found in comparison of the surface per unit volume and the cooling velocity and not in consideration of the amount of surface alone.

While the surface-cooling velocity curves shown in Fig. 30 for the different shapes are of the same general form as those in Fig. 29, in which diameter or thickness is plotted against the cooling velocity, it can readily be shown that they apply only to the specific sets of conditions covered by the experiments and are not of most

general use. Therefore, no attempt has been made to represent these curves mathematically.

4. RELATION BETWEEN THE SURFACE PER UNIT OF VOLUME AND THE CENTER COOLING VELOCITY, TAKEN AT 720 DEGREES CENT. (1330 DEGREES FAHR).

If the cooling velocity, taken at 720 degrees Cent., is compared to the surface per unit of volume for each of the basic shapes (spheres, rounds, and plates) a family of hyperbolic curves is obtained which are represented by the equation

$$V = \left(\frac{S}{W} \right)^n \times C_2 \quad (7)$$

in which V is the cooling velocity in degrees Centigrade per second, taken at 720 degrees Cent., S is the surface area in square inches, W is the volume in cubic inches and " n " and " C_2 " are constants, the values of which are given in Table V. (" n " is the same as in previous equations.)

Table V
Numerical Values of the Constants for Equation (7)

Conditions	Value of	
	" n "	" C_2 "
Rounds quenched in 5 per cent NaOH from 875° C.	1.84	3.86
Spheres quenched in water from 875° C.	1.75	3.89
Rounds quenched in water from 875° C.	1.75	3.91
Plates quenched in water from 875° C.	1.75	4.03
Average. ....	...	3.94
Spheres quenched in No. 2 oil from 875° C.	1.40	3.22
Rounds quenched in No. 2 oil from 875° C.	1.40	3.03
Average. ....	...	3.12
Rounds cooled in air from 875° C.	1.15	.31

Unlike previously developed relations both constants are independent of the shape of the material and under otherwise fixed conditions are determined solely by the coolant. This, however, only applies to the simple and basic shapes covered by the experiments, namely, spheres, rounds, and plates, but is not restricted to a fixed ratio of length to diameter in the rounds or a fixed ratio of length to width to diameter in the plates. Equation (7) is thus more generally applicable than the previous ones. Experimental confirmation of this is given in Fig. 31, in which is shown the effect of surface per

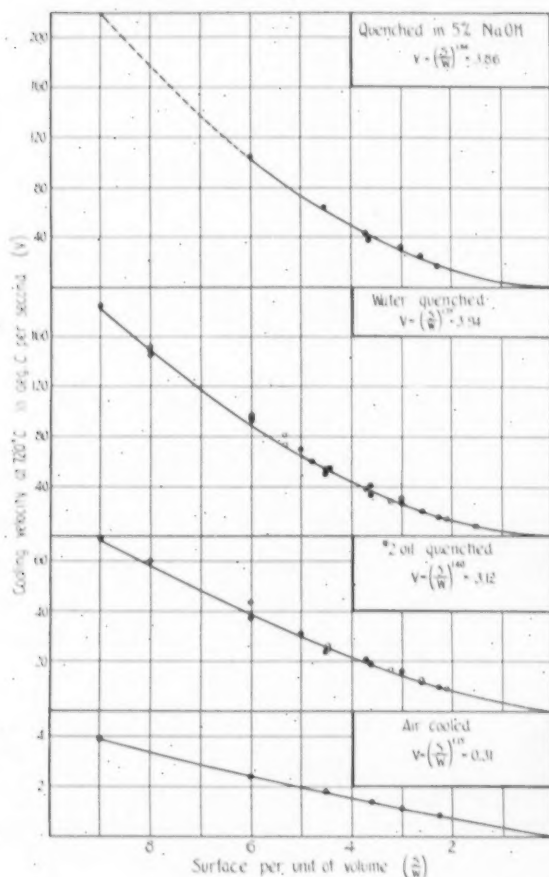


Fig. 31—Relation Between the Surface Per Unit of Volume and the Center Cooling Velocity, Taken at 720 Degrees Cent. in Various Sizes and Shapes Quenched from 875 Degrees Cent. Into Different Coolants.
Hollow Circles Represent Determinations With Spheres; Solid Circles With Rounds; Hollow Squares With Plates.

unit volume on the cooling rates in various coolants. Spheres, rounds with different ratios of length to diameter, and plates in which the ratio of length to width to diameter has been varied are all plotted to the same coordinates and fall closely on a smooth curve for each coolant. From the data given in Fig. 31 it is possible to approximate the cooling velocity for any of the simple basic shapes, or this can be determined from equation (7) and the values of "n" and "C₂" given above for 5 per cent sodium hydroxide in water, water, a commercial quenching oil, and air cooling. If the critical cooling rates are known for a given steel, or quenching diagrams are available, it follows that the degree of hardening can be predicted or that the size which will

harden completely throughout (martensitization) can be determined, whether for a round, sphere, plate, or cube.

Inasmuch as " n " and " C_2 " of equation (7) are independent of the shape of the material, the center cooling velocities of spheres, rounds, and plates will be equal when their respective surfaces per unit of volume are equal. The sizes which have equal surfaces per unit of volume in these different shapes, and, hence, equal center cooling velocity, are as follows:

Size in inches for—		
Length-diameter ratio for rounds	4:1	Infinite
Length-width-thickness ratio for plates	4:4:1	Infinite
Spheres	4	3
Rounds	3	2
Plates	2	1

The difference between these ratios for the finite and the infinite specimens is due to the greater cooling effect exerted by the end and edge surfaces of the short pieces.

To apply the foregoing to any coolant it is only necessary to know, for different values of surface per unit of volume, the relation between " n " and the cooling velocity. This is shown graphically by the family of curves in Fig. 32 and can conveniently be used for any of the simple shapes. For example, if the prescribed cooling velocity is known when quenching a cylinder 1 inch in diameter and 6 inches long in a special oil, the numerical value of " n " for this coolant is given by the intersection of the horizontal line at this cooling rate and the curve representing the surface per unit of volume of a 1-inch round by 6-inch long cylinder. Let it be assumed that the cooling velocity is known to be 25 degrees Cent. per second. Since the surface per unit of volume of the designated cylinder is 4.33, the value of " n " equals 1.43.

By substitution in equation (7) the constant " C_2 " can readily be obtained, and it is then possible to make use of the equation in the usual manner. However, the determination of " C_2 " is not necessary. Knowing the value of " n " for the coolant, it is possible to obtain directly from the curves in Fig. 32 the cooling velocity for any value of surface per unit of volume. These lie along a vertical line projected from 1.43 which equals the value of " n ".

Fig. 32 gives the most useful of the relationships so far described for with it a close approximation can be obtained of the "mass effects" in quenching for a wide range of conditions. No calculations

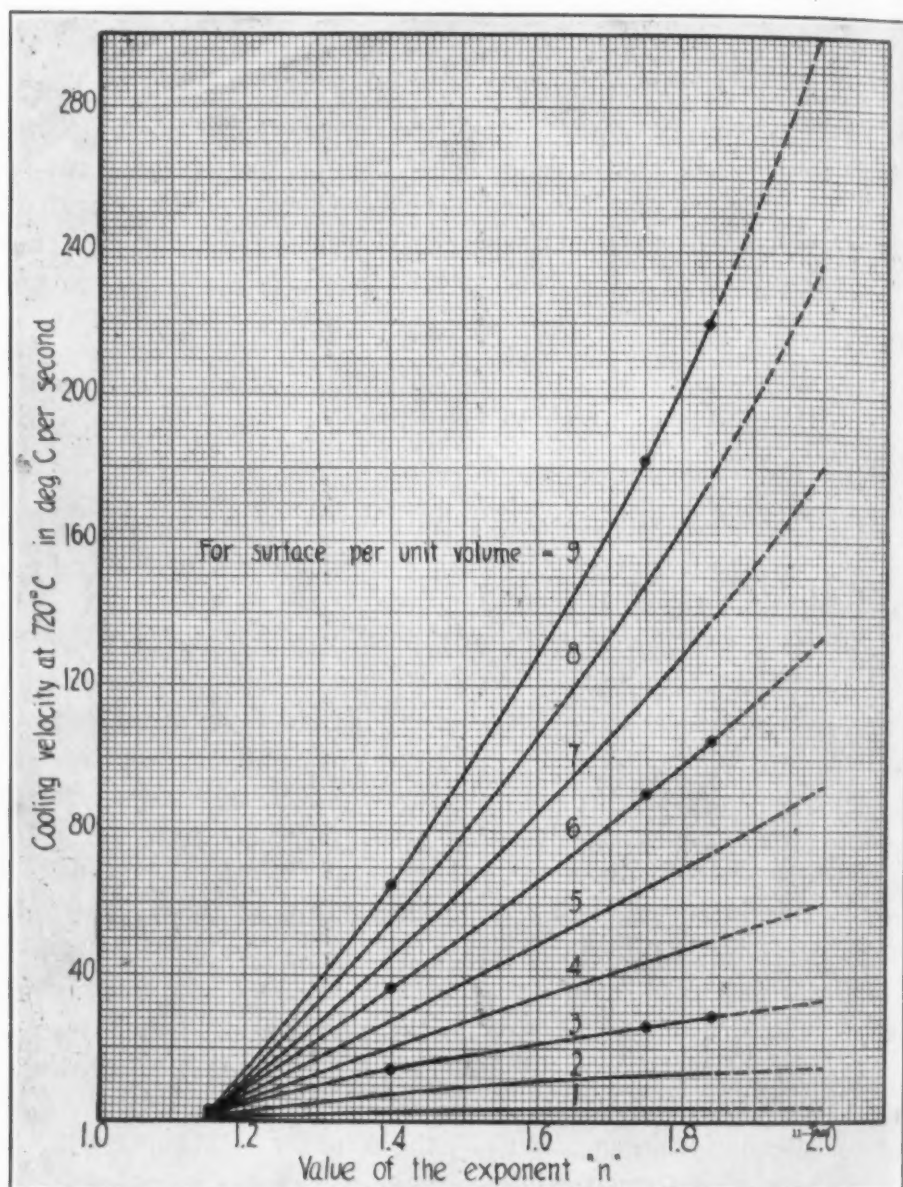


Fig. 32—Mass Effect Chart.

This Gives the Relation Between the Center Cooling Velocity, Taken at 720 Degrees Cent., the "n" of Equation (7), and the Surface Per Unit of Volume for High-Carbon Steels Quenched from 875 Degrees Cent. Into Any Coolant.

are required, and it is only necessary to know the center cooling velocity for one size in any of the simple shapes.

It will be well at this point to refer again to the conditions under which the experiments were carried out, so that there will be no misunderstanding concerning the application of the described data. In

the first place, the equations apply only to the center of the simple shapes. In all cases a quenching temperature of 875 degrees Cent. (1605 degrees Fahr.) was employed, and both the steel and the coolant were kept motionless. As the customary methods of commercial heat treatment involve agitation or circulation of liquids, such as water and oils, and likewise a variety of quenching temperatures are employed depending largely upon the composition of the

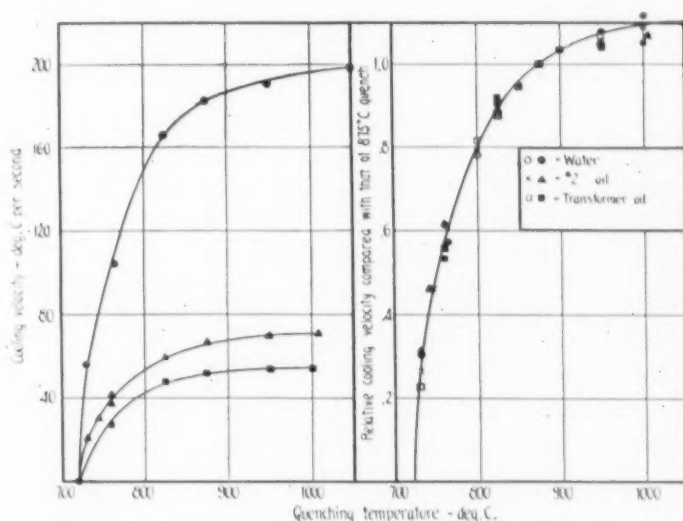


Fig. 33—Effect of Quenching Temperature on the Center Cooling Velocity, Taken at 720 Degrees Cent. in Quenching High-Carbon Steel Into Either Motionless Water or Oils at 20 Degrees Cent.

Direct Experimental Results Given as Solid Circles, Triangles, and Squares. Derived Values, as Explained in the Text, are Shown by Crosses and Hollow Circles and Squares.

steel, but also on the purpose of the treatment, practical application of the data requires consideration of the effect of motion in coolants and of the effect of quenching temperature on the cooling velocity.

Just as water and oil are different coolants so may each rate of motion or degree of circulation be properly considered as distinct from the motionless coolant. The rate of coolant motion is known to change the speed of cooling and there are, therefore, an infinite variety of coolants which must be considered, including not only changes in the composition but also in degree of motion and temperature. However, it is only necessary to know the cooling velocity for one size and shape of sample when quenched from 875 degrees Cent. (1605 degrees Fahr.) in order to determine from Fig. 32 the constant "n" and all data which can be developed for the motionless media used in the experiments. The accuracy of the results will, of

course, be dependent upon the reliability of the cooling rate used as a basis for the comparisons or calculations. It may now be stated that:

(f) In quenching simple shapes of various sizes (spheres, rounds, plates) the center cooling velocity is proportional to some power of the surface per unit of volume greater than 1 and less than 2. This power increases with the rapidity of the coolant used.

(g) When quenching from a definite temperature into a given coolant the center cooling velocity is determined by the exposed surface per unit of volume. Hence, it will be equal in spheres, rounds and plates which have equal surface per unit of volume. This condition is fulfilled when the ratio of diameters of spheres and rounds of infinite length to the thickness of plates having infinite width and length is 3:2:1. When the length of the round is four times its diameter and the width and length are each four times the thickness of the plate, these ratios become 4:3:2.

5. EFFECT OF QUENCHING TEMPERATURE ON THE CENTER COOLING VELOCITY, TAKEN AT 720 DEGREES CENT. (1330 DEGREES FAHR.)

The effect of quenching temperature on the designated cooling velocity obtained in water and two oils is shown graphically at the left side of Fig. 33, and it will be noted that in all cases the increase in rate is much more marked for a given temperature rise between 720 and 800 degrees Cent. (1330 and 1470 degrees Fahr.) than above. From these curves conversion factors can be determined by which it is possible to change the cooling rates from the "standard" quenching temperature of the experiments, 875 degrees Cent., into the rates which would be obtained from any initial temperature between 720 and 1050 degrees Cent. (1330 and 1920 degrees Fahr.) a range covering commercial hardening temperatures except for high speed steels. As a matter of convenience the conversion factors are shown graphically in the right half of the diagram.

In addition to the direct experimental observations giving the changes in rates with quenching temperature, derived values for the conversion factors have been included in the curve at the right side of Fig. 33. These were computed from data given in Fig. 21 and depend upon two facts—(1) that the cooling velocity-temperature changes (neglecting thermal transformations) are of the same form when quenching the various sizes and shapes from different temperatures in a given coolant, and (2) for a given final temperature the maximum velocity throughout the cooling ranges is directly proportional to the initial (quenching) temperature, both with respect to its position in the temperature scale and its numerical value.

The many quenching curves taken to demonstrate these features cannot be included in this paper, nor will there be given in detail

the derivation of the conversion factors by this method. It is to be noted, however, that the derived values show close agreement with those determined directly by experiment, and thus indicate that exceptionally consistent results have been obtained in the several sets of experiments.

The actual change in cooling velocity is larger in the rapid coolant than in those which cool the steel more slowly, but the conversion factors for the two oils and water are practically identical—at least, they are so close as to be within the limits of experimental accuracy.

From the data given in Fig. 33 “the quenching temperature conversion chart” of Fig. 34 was prepared. This gives for samples of different surfaces per unit of volume the conversion factors to be applied to the cooling velocity from one quenching temperature in order to determine the cooling velocity of the same sample when quenched in the same coolant from other temperatures between 720 and 1050 degrees Cent. (1330 and 1920 degrees Fahr.)

It should apply generally to coolants which give cooling characteristics similar to those shown in Fig. 21. Practically all of the oils and aqueous solutions tested at ordinary temperatures fulfill these conditions within the limits of accuracy attained in the described experiments. Included in this list are sodium hydroxide solutions, sodium, and also calcium chloride brines, dilute sulphuric acid, sperm, neat's-foot, transformer, cottonseed, machine, castor, olive, fish, and three proprietary quenching oils. It does not, however, apply to air cooling.

In connection with Fig. 34 the “mass effect chart” (Fig. 32) becomes of general use, as it is only necessary to reduce the known value of the cooling velocity from one quenching temperature into the rate produced from 875 degrees Cent. (1605 degrees Fahr.) when the “mass effects” can be determined and a reversion for quenching temperature made for the new size and shape. To illustrate the use of the “quenching temperature-conversion” chart, a number of examples may be cited.

If the rate for a $\frac{1}{2}$ -inch round, 2 inches long (surface per unit volume = 9) is known to be 67 degrees Cent. per second when quenched in a given coolant from 900 degrees Cent. (1650 degrees Fahr.) and it is desired to determine the rate when quenching from 760 degrees Cent. (1400 degrees Fahr.) under otherwise comparable conditions, the following procedure may be employed:

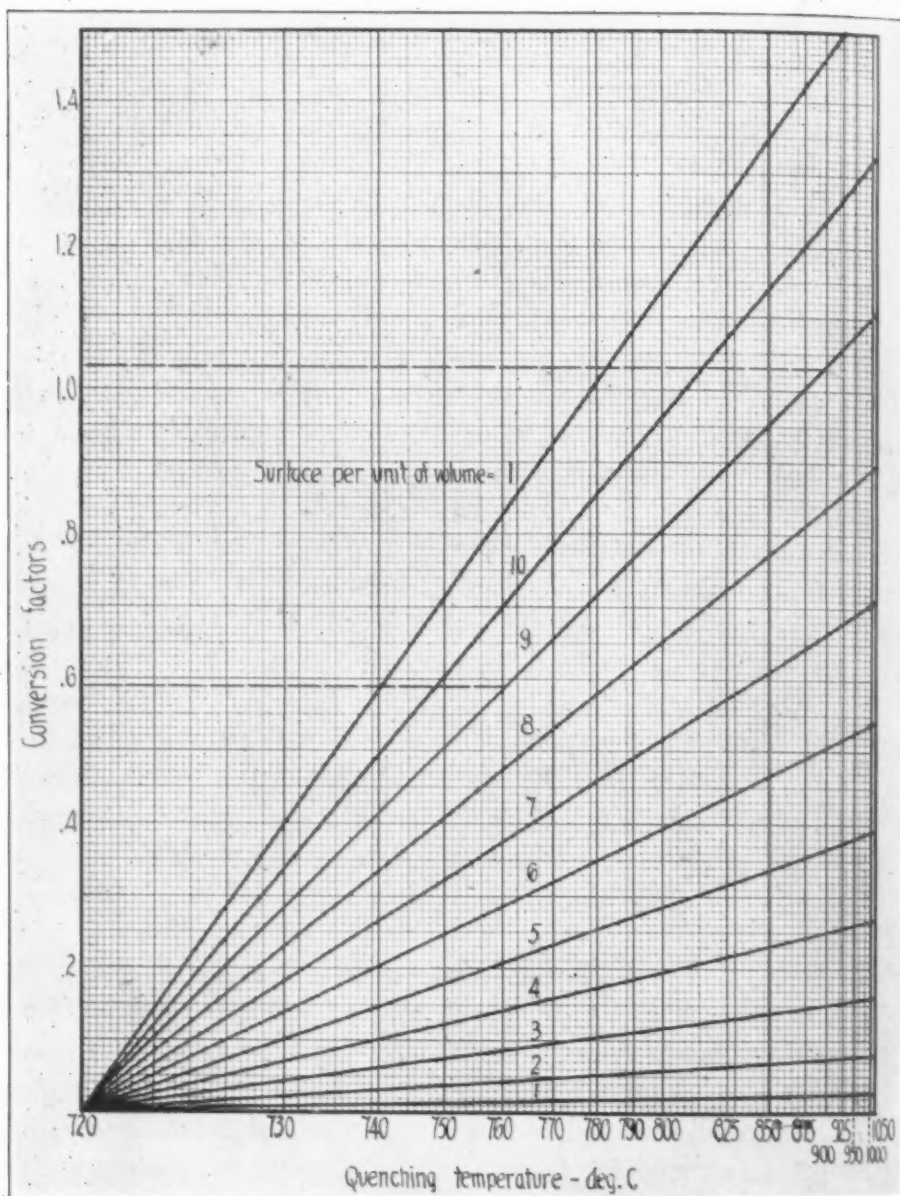


Fig. 34—Quenching Temperature Conversion Chart.

This Gives the Relation Between the Quenching Temperature and Center Cooling Velocity Taken at 720 Degrees Cent., for Various Sizes and Shapes of Steel With the Oils and Aqueous Solutions Having Cooling Characteristics Similar to Those Shown in Fig. 20.

First obtain in Fig. 34 the intersection between the $\left(\frac{S}{W}\right)$ curve=9 with the quenching temperature of 900 degrees Cent. The factor opposite this intersection is 1.03. Next follow the $\frac{S}{W}$ curve=9 in the direction of, and until it intersects, the new quenching temperature of 760 degrees Cent. The

factor opposite this intersection is 0.59. The cooling velocity when quenching from 760 degrees Cent. will then be $\frac{0.59}{1.03}$ of that when quenching from 900 degrees Cent. or $\frac{0.59}{1.03} \times 67 = 38$ degrees Cent. per second.

The described procedure is shown by the dotted lines in the chart.

A more complicated case in which both the "mass effect" and "temperature conversion" charts are used will now be followed and checked by direct experimental data.

The selected cooling velocity for a $\frac{3}{4}$ -inch round, 3 inches long (surface per unit of volume = 6), when quenched from 790 degrees Cent. (1455 degrees Fahr.) into 5 per cent sodium chloride was found by experiment to be 76 degrees Cent. per second. It is desired to determine the cooling velocity in a $\frac{1}{2}$ -inch round, 2 inches long (surface per unit of volume = 9), when quenched from 875 degrees Cent. (1605 degrees Fahr.) into the same coolant. The following procedure may be used:

1. First make the temperature conversion from 790 to 875 degrees Cent. from Fig. 34.

Find the intersection between the curve $\frac{S}{W} = 6$ and the quenching temperature of 790 degrees Cent. The factor opposite is 0.37. Next follow on this $\frac{S}{W}$ curve to the right until it intersects 875 degrees Cent. The factor opposite this intersection is 0.49. The cooling velocity when quenching the $\frac{3}{4}$ -inch round 3 inches long from 875 degrees Cent. will then be $\frac{0.49}{0.37} \times 76 = 101$ degrees Cent. per second.

2. Convert this new cooling rate of 101 degrees Cent. (213 degrees Fahr.) per second for the $\frac{3}{4}$ -inch round into the rate for the $\frac{1}{2}$ -inch round from Fig. 32.

Find the intersection of the line representing the surface per unit of volume of the $\frac{3}{4}$ -inch sample (=6) with the cooling rate of 101 degrees Cent. per second. Follow vertically from this point to the new surface per unit of volume (=9 for the $\frac{1}{2}$ -inch round). The intersection is found to be opposite to a cooling velocity of 211 degrees Cent. per second.

The cooling rate obtained experimentally for the described conditions was found to be equal to 215 degrees Cent. per second, which checks the value derived from the two charts (211 degrees Cent. per second), within about 2 per cent.

Other comparisons between values derived from the two charts and experiment are given in Table VI and show that consistent results are secured.

Table VI

Comparison of Direct Experimental Determination for Cooling Velocity Taken at 720 Degrees Cent. with Values Derived from "Mass Effect" and "Quenching Temperature Conversion" Charts (Figs. 32 and 34)

Sample 1	Surface per unit volume 2	Coolant 3	Quench- ing tempera- ture 4 ° C.	Cooling velocity at 720° C., by experi- ment 5	Cooling velocity at 720° C. when quenching from 875° C.		Variation of (6) from (7) 8 Per cent
					Con- verted S to W by means of Tables 8 and 10 6	Direct experi- mental deter- mina- tion for S W 7	
3/4 by 3 inch round	6	5 per cent NaCl	790	76	211	215	2
3/4 by 3 inch round	6	H ₂ O	800	69	174	182	4.5
3/4 by 3 inch round	6	Transformer oil	790	19	54	51	5.5
2 + 3/4-inch sphere	2.1	H ₂ O	760	8.3	186	182	2
2 + 3/4-inch sphere	2.1	No. 2 oil	760	4.6	65	66	1.5

6. GENERAL LIMITS WITHIN WHICH THE DERIVED RELATIONS BETWEEN THE COOLING VELOCITY AND SURFACE PER UNIT OF VOLUME APPLY

The results of a few special experiments will serve to illustrate the limits within which the derived relations between the cooling velocity and surface per unit of volume apply.

A 1-inch diameter cylinder, 3½ inches long, with spherical ends was quenched in water from 875 degrees Cent. and the center cooling velocity found to be 55 degrees Cent. per second. This cylinder has a surface per unit of volume equal to 4.42 and according to equation (7) the cooling velocity would be 53 degrees Cent. per second. Its surface per unit of volume is slightly less than the same cylinder without the spherical ends (4.56) for which a cooling velocity of 56 degrees Cent. per second should be obtained.

A 7/8-inch square bar 3 inches long when similarly quenched in water from 875 degrees Cent. had an experimentally determined cooling rate equal to 60 degrees Cent. per second. Its surface per unit of volume equals 4.80 and according to equation (7) or the chart reproduced in Fig. 32 its velocity should be 61.

In both these cases the modifications made in the basic shapes (spheres, rounds, and plates) did not involve very large changes in the surface per unit of volume, and the values obtained from the equations and charts check the experimental data within the limits of accuracy attained. Therefore, a 3/4-inch diameter cylinder, 3

inches long, was prepared in which the entire curved surface was threaded with $\frac{3}{4}$ -inch United States standard threads, 10 to the linear inch. The surfaces per unit of volume of this threaded specimen and an unthreaded cylinder of the same length and diameter are respectively 11.0 and 6.0. The calculated cooling velocity for the threaded piece was 262 degrees Cent. (505 degrees Fahr.) per second, whereas the actual rate obtained in quenching it was only 92 degrees Cent. per second, which is practically identical with the calculated and actual cooling velocity of the plain cylinder, namely, 90 degrees Cent. per second.

General conclusions should not be drawn from these limited experiments, but they indicate that the described relations between cooling velocity and the surface per unit of volume do not apply when modifications in the simple basic shapes involve a large change in the surface without appreciably affecting the volume (or weight). With slight changes in form from the basic shapes which do not alter materially the ratios of surface to volume the equations and charts give results which approximate the actual values within about 5 per cent.

Obviously, they cannot be considered for irregularly shaped masses which have no geometrical center at which to determine the cooling velocity, but in at least some of such cases it is reasonable to expect that the cooling velocity at the center of equal temperature planes would bear some definite relation to the surface-volume relationship. This might profitably be investigated, but would require a study of temperature distribution during cooling.

An important question, as it relates to the simple shapes covered by the experiments, is whether the data can be applied to large masses.

It has already been demonstrated that the relation between the center cooling velocity and the surface per unit of volume is represented by a family of hyperbolic curves having the general equation

$$V = \left(\frac{S}{W} \right)^n c_2$$
 As the value of the exponent "n" was found to vary for the different coolants, the curves will cross if carried far enough to include very large sizes.

In other words, oil would cool faster than water, and with sufficiently large masses even air would cool the center more rapidly than sodium hydroxide, etc. Obviously, such effects are unreasonable, and it may be stated at the outset that the several equations do not hold good in such cases. However, it is quite reasonable for the center

cooling velocity obtained in various coolants to be more nearly the same for large sections than in the relatively small samples used in the described experiments. A point must be reached with increasing mass where the effective surface through which the heat must be taken is so small in relation to the weight (or volume) and so far removed from the center that the cooling is a function of the thermal proper-

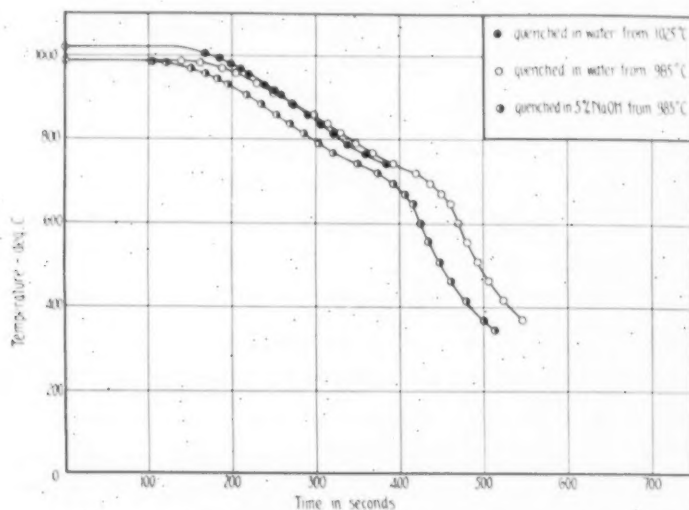


Fig. 35—Time-Temperature Cooling Curves Obtained at the Center of a $11\frac{1}{4}$ -Inch Diameter Sphere Quenched in Various Coolants From Different Temperatures.
This Sphere Was Made From 0.19 Per Cent Carbon Steel.

ties of the metal. No matter how quickly the surface is brought to the final temperature of cooling there must be a limiting rate by which heat can be withdrawn from the center, and this is controlled by the thermal properties of the material being quenched.

a. *Results Obtained in Quenching a Sphere $11\frac{1}{4}$ Inches in Diameter*

To determine whether equal cooling velocities are obtained under such conditions, in which the equations show a supposed reversal of "hardening power" for various coolants, and likewise to compare the numerical values of cooling rates determined experimentally on large sections with those derived from the small size specimens, three quenching experiments were carried out with a sphere 11.25 inches in diameter. This was quenched from 985 and 1025 degrees Cent. (1805 and 1875 degrees Fahr.) into motionless water at 22 degrees Cent. and also from 985 degrees Cent. (1805 degrees Fahr.) into

motionless 5 per cent sodium hydroxide at 22 degrees Cent. A 14-gage chromel-alumel thermocouple and a portable potentiometer were used in taking the time-temperature cooling curves reproduced in Fig. 35. Aside from the inconvenience in using the string galvanometer for low rates of cooling this change in equipment and methods was desired to check the accuracy of the determinations on the small samples. Special precautions were taken to maintain good contact between the thermocouple and the center of the sphere during both heating and cooling. The thermocouple was mounted on a threaded plug in such a manner that when screwed tightly into the hole bored to the center of the sphere it pressed the hot junction against the metal.

Mention has already been made of the fact that the maximum cooling velocity throughout the cooling range is directly proportional, both with respect to its position in the temperature scale and its numerical value to the initial (quenching) temperature (provided the coolant and its temperature are fixed). In both water and 5 per cent sodium hydroxide the maximum velocity is found at about 0.8 of the quenching temperature. This, therefore, offers a simple method of comparison which will be used in discussion of the quenching of the large sphere.

When quenched in water from 985 degrees Cent. (1805 degrees Fahr.), the maximum center cooling velocity was found to be 1.4 degrees Cent. per second (at 790 degrees Cent.); from 1025 degrees Cent. it was 1.5 degrees Cent. per second (at 820 degrees Cent.); quenched in the 5 per cent sodium hydroxide from 985 degrees Cent., it was 1.4 degrees Cent. per second.

Thus, the maximum cooling velocity determined directly by experiment at the center of the 11.25-inch diameter sphere was the same when quenched in water as in the 5 per cent sodium hydroxide.

The surface per unit of volume of this sphere is 0.533. From the "mass effect chart" (Fig. 32) or equation (7) the maximum cooling velocity can be computed as in quenching from 875 degrees C.,

it occurs at from 700 to 720 degrees Cent. These values times $\frac{985}{875}$

will then give the respective maximum rates when quenching from 985 degrees Cent. A comparison of the derived values and the experimental data follows:

	Maximum cooling velocity, ° C. per second	
	Derived value	Experimental value
Quenched from 985 degrees Cent.:		
Into 5 per cent NaOH	1.35	1.4
Into water	1.40	1.4
Quenched from 1025 degrees Cent.:		
Into water	1.52	1.5

An exceedingly close check has been obtained. However, the important feature is that water and 5 per cent sodium hydroxide do not, as in the case of the small samples, give appreciably different center cooling velocities.

It is not, of course, possible from these experiments to set definite limits within which the "mass effect chart" (Fig. 32) or the hyperbolic curves between center cooling velocity and surface per unit of volume hold good. However, it appears that these curves are valid, within the prescribed limit of accuracy of about 5 per cent, at all points until they cross the curve for water which is represented by the equation

$$V = \left(\frac{S}{W} \right)^{1.75} \times 3.94;$$

subsequently as the size increases the velocities in other media appear to approximate those given by water which has been shown to apply to large masses.

It should now be evident why the exponent "n" of the several equations cannot be used as a direct measure of the "hardening power" of coolants, for in large sections, as was shown by the experiments just described, little difference is observed in the center cooling velocity for widely different coolants. In such cases the cooling is a function of the thermal properties of the metal.

7. COMPUTATION OF CENTER COOLING CURVES FROM THE EXPERIMENTAL DATA

If in equation (6) there is substituted the value of V given by equation (7) the following is obtained.

$$T = \frac{CC_1}{C_2} \left(\frac{W}{S} \right)^n \quad (8)$$

Since C, C₁ and C₂ are constants, the product of C and C₁ divided by C₂ will also be a constant. Equation (8) may then be rewritten as follows:

$$T = C_3 \left(\frac{W}{S} \right)^n \quad (9)$$

This shows that the cooling time for a given temperature change at the center of small sizes of the simple shapes is proportional to the reciprocal of the surface per unit of volume raised to some power "n." The numerical values of this exponent have already been determined for a number of coolants and found to vary be-

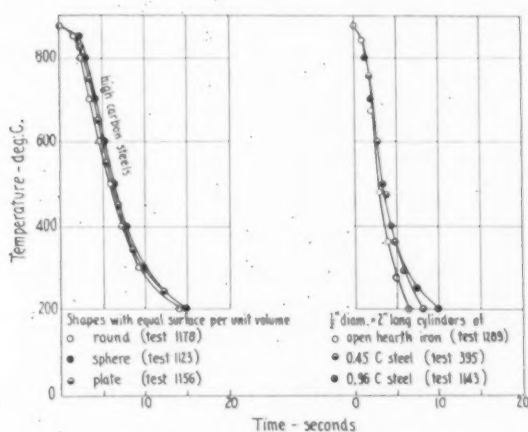


Fig. 36—Effect of Composition of Steel and Shape of Sample on Time-Temperature Cooling Curves Taken at the Center of Small Masses.

tween 1 and 2; methods for determining the value of "n" for other coolants have also been outlined. To apply equation (9) it is then only necessary to evaluate the constant C_3 and determine upon what variables in quenching it is dependent in addition to the cooling range selected. With the evaluation of the constant C_3 it should be possible to construct the complete time-temperature cooling curve for the center of various sizes and shapes.

In the experiments with samples of different sizes and shapes all small samples used in the experiments were made of high carbon steels or high carbon-chromium steels, whereas the largest sections were by force of circumstance prepared from commercial low carbon steels. These variations in steel composition are undesirable, especially from the standpoint of the cooling at the lowest temperatures, for, as is shown at the right side of Fig. 36, they introduced variations in the cooling. With low carbon steels the cooling was more rapid in the range below about 500 degrees Cent. but at the higher temperatures such changes in composition produced changes in the cooling which were small and not easy to measure by the

methods used in the investigation. It should, therefore, be kept in mind that the numerical values for certain constants later developed will give at the lower portions of the cooling range times slightly large for small sections of low carbon steel and times which are somewhat low for large sections of high carbon steels.

It has already been shown that the cooling velocity in the neighborhood of 720 degrees Cent. is dependent upon the surface per unit of volume and does not vary with the shape of sample. Likewise, it has been shown that the cooling times for certain temperature intervals is inversely proportional to the cooling velocity. At the left side of Fig. 36 it is shown that, within limits of experimental error, the entire cooling is independent of the shape of sample. While this has been determined only on small and moderate-size sections, it is a reasonable assumption that this applies equally to the large specimens. Further indirect evidence of this will be found in data presented later.

a. Data Showing That in a Given Coolant the Center of a Given Steel Sample Cools in Equal Times to Equal Proportions of the Cooling Range

Before considering in detail the relations between cooling times and the size and shape of sample, attention will be given to the effect of variations in quenching temperature on the cooling. The times required to cool the center of spheres of different sizes from 730° (or 760°), 815°, 875°, and 950 degrees Cent. to various lower temperatures in water, No. 2 oil and air are summarized in Tables VII and VIII. If these times are plotted against temperature expressed as a proportion of the cooling range (quenching temperature to coolant temperature), curves similar to those in Fig. 37 are obtained.¹⁷ It will be observed that the center of the sample cools to equal proportions of the cooling range in equal times. It therefore follows that any relations developed for one initial temperature are immediately applicable to any other, provided only that temperature is expressed as a proportion of the cooling range. However, this has only been shown to apply to quenching from above the transformations, at or above about 720 degrees Cent.

¹⁷For coolants at atmospheric temperatures, no appreciable error is introduced and calculations are simplified if temperatures are expressed as a proportion of the temperature of quench instead of as a proportion of the cooling range. This method was used in plotting Figs. 37 and 41 and in deriving data in Tables VII and IX, relating to coolants at ordinary temperatures. It will introduce greater errors for coolants at much higher temperatures.

Table VII

Effect of Quenching Temperature on the Center Cooling of Steel Specimens of Various Sizes and Shapes in Different Media

Size, Inches	Run No.	Coolant	Quench Temp. ° C.	Time in Minutes to Cool to Proportion of Quenching Temperature Indicated ¹							
				97.2	91.4	80.0	68.6	57.2	45.7	34.3	22.9
				%	%	%	%	%	%	%	%
2 3/4 Sph.	1322	Water	760	0.21	0.30	0.39	0.49	0.61	0.76	0.93	.....
1 1/2 x 2 Rd.	1324	Water	760	0.018	0.026	0.035	0.044	0.055	0.068	0.093	.....
1 1/2 x 2 Rd.	1325	Water	760	0.017	0.024	0.033	0.043	0.052	0.063	0.082	.....
2 3/4 Sph.	1333	No. 2 Oil	760	0.28	0.43	0.63	0.84	1.13	1.62	.....	.....
1 1/2 x 2 Rd.	1331	No. 2 Oil	730	0.025	0.038	0.064	0.095	0.145	0.255	0.487	.....
1 Sph.	1495	Air	760	0.18	0.53	1.30	2.25	3.31	5.60	8.30	13.0
1 1/4 Sph.	1496	Air	760	0.25	0.75	1.85	3.33	5.42	6.47	12.22	18.50
1 Sph.	1509	Water	815	0.029	0.048	0.068	0.089	0.111	0.139	0.188	0.270
1 1/8 Sph.	1510	Water	815	0.088	0.139	0.192	0.256	0.323	0.402	0.520	0.780
2 3/4 Sph.	1511	Water	815	0.203	0.292	0.413	0.542	0.673	0.817	0.992	1.25
3/4 Sph.	1489	No. 2 Oil	815	0.033	0.050	0.077	0.111	0.163	0.258	0.427	0.883
1 1/8 Sph.	1491	No. 2 Oil	815	0.087	0.125	0.192	0.278	0.422	0.622	1.07	.....
1 1/8 Sph.	1492	No. 2 Oil	815	0.15	0.205	0.300	0.437	0.637	0.933	1.52	.....
2 3/8 Sph.	1493	No. 2 Oil	815	0.20	0.28	0.46	0.66	0.903	1.27	2.12	.....
3/4 Sph.	1488	Air	815	0.133	0.327	0.783	1.53	2.6	4.0	5.93	9.5
1 Sph.	1487	Air	815	0.183	0.408	1.07	2.10	3.58	5.43	8.08	12.42
1 1/8 Sph.	1486	Air	815	0.30	0.667	1.63	3.15	5.38	8.33	12.2	18.33
1 1/8 Sph.	1485	Air	815	0.39	0.92	2.33	4.55	7.80	12.25	18.2	28.00
2 3/8 Sph.	1484	Air	815	0.52	1.17	2.97	5.67	9.75	15.50	26.67	36.67
2 3/4 Sph.	1483	Air	815	0.72	1.52	3.71	7.32	12.67	20.37	30.00	48.00
1 1/8 Sph.	1513	Water	950	0.080	0.110	0.150	0.183	0.219	0.263	0.325	0.423
2 3/8 Sph.	1514	Water	950	0.146	0.223	0.313	0.403	0.500	0.620	0.771	1.029
2 3/8 Sph.	1507	No. 2 Oil	950	0.187	0.300	0.445	0.607	0.817	1.17	1.83	3.37
2 3/4 Sph.	1508	No. 2 Oil	950	0.233	0.383	0.670	0.767	1.03	1.45	2.33	4.00
3/4 Sph.	1497	Air	950	0.117	0.270	0.667	1.22	2.17	3.57	5.40	8.50
1 Sph.	1498	Air	950	0.183	0.453	1.11	2.03	3.63	5.95	8.92	13.63
1 1/8 Sph.	1499	Air	950	0.267	0.667	1.58	2.97	5.27	8.75	13.58	21.00
2 3/4 Sph.	1501	Air	950	0.482	1.000	2.50	4.78	6.65	14.87	23.33	36.50
2 3/4 Sph.	1502	Air	950	0.617	1.28	3.03	5.88	10.67	18.37	29.00	45.17

¹For example, the range from 1000-600 degrees Cent., when quenching from 1000 degrees Cent., is given as 60 per cent. (Refer to footnote 17 of the text.)

b. Evaluation of the "Time-Constant"

In Table VIII are tabulated the times required for cooling from 875 degrees Cent. to various lower temperatures. These numerical values were secured from a large number of cooling curves taken when quenching the specified sizes and shapes into water, No. 2 oil and air. Included also are values taken from curves for large sections published by Law¹⁸ and Bash¹⁹; Harper's data have not yet been published.²⁰ From these data, the values of C_3 in equation (9) were computed and it was found that its numerical value depended not only upon the coolant and the cooling

¹⁸E. F. Law: Effect of Mass on Heat Treatment. *Journal, Iron and Steel Institute*, 97, 333 (1918).

¹⁹F. E. Bash: Forging Temperature and Rate of Heating and Cooling of Large Ingots, *Transactions, American Institute of Mining and Metallurgical Engineers*, "Pyrometry Volume," p. 614 (1920).

²⁰The cooling curves at the center of the 12-inch cube quenched in water and also cooled in air were taken from experiments recently carried out by J. F. Harper, Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin.

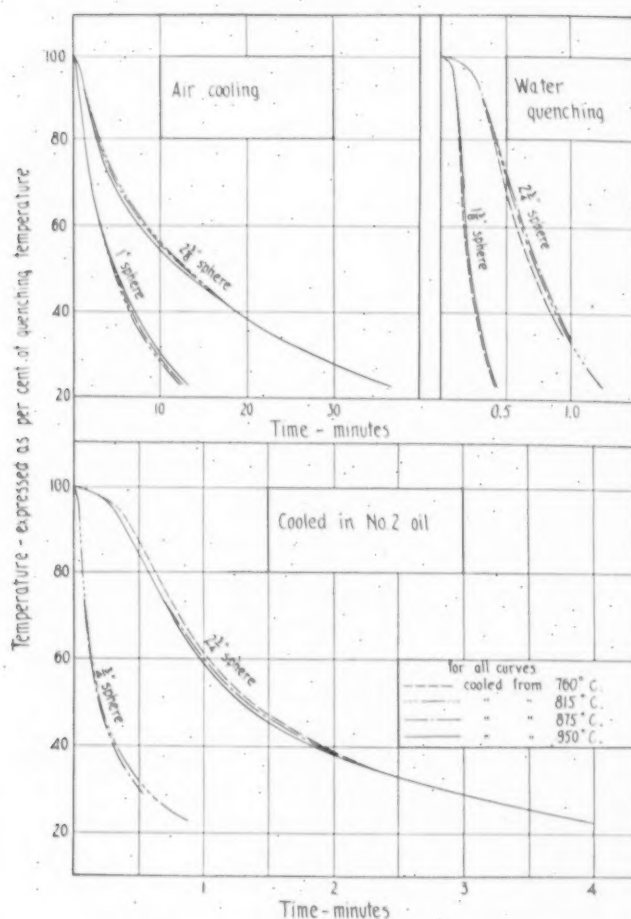


Fig. 37—Effect of Quenching Temperature on the Center Cooling Curves of Steel Samples Immersed in Various Coolants.

Note that all Temperatures are Expressed as a Proportion of the Initial (Quenching) Temperature: (Refer to Footnote 17 of the Text.)

interval, but also upon the surface per unit of volume. Under such conditions the direct evaluation of this constant for even one coolant involves a great deal of work, including such extensive experiments that when completed they make the evaluation unnecessary, for there have been obtained experimentally all required data. For this reason, the results of the computations referred to are not here included.

Obviously what is needed is to evaluate C_s in terms of readily determinable factors associated with the surface per unit of volume and the coolant, so that with a cooling curve for the center of one size of the simple shapes immersed in a given coolant

curves can be derived by means of simple calculations for various sizes and shapes when quenched in the same coolant.

It is unnecessary to record in detail the methods by which these relations were developed, but one feature should be mentioned. With the exception of the first drop in temperature, say for an interval of 20 degrees Cent., the cooling curves for the various sizes appeared to follow closely the relations represented by equation (9). More specifically, when deriving time-temperature cooling curves for the center of large sections from constants determined from experiments on small samples it was found that the derived curves were in most cases generally parallel to, but offset at some distance from, the curves determined experimentally. The derived curves in practically all cases showed more rapid cooling than was observed directly by experiment, and the magnitude of this difference appeared to increase with the section, and hence with decrease in the surface per unit of volume.

Consider, for a moment, that heat is first taken away from the surface and an appreciable time elapses before there can be an appreciable drop in temperature at the center. In small sizes

(high values of $\frac{S}{W}$) where the most rapid cooling is obtained, this difference should be small, whereas in the relatively large sections (small values of $\frac{S}{W}$) where the surface is far removed from the center, it should be large.

It is difficult to determine the time required for the first small temperature drop at the center. Therefore this factor, which will hereafter be called "lag," will be defined for present purposes as the time required for a temperature drop of 2 per cent of the cooling range (equals 17.1 degrees Cent. for a quenching temperature of 875 degrees Cent. when the coolant is at 20 degrees Cent.). Actually the "lag" increases with decrease in the surface per unit of volume, and hence with increase in size of any one of the simple shapes (refer to Fig. 20).

With these effects in mind, a study of the experimental data summarized in the various tables and charts gave the following empirical relations:

$$T - x = y \left(\frac{W}{S} \right)^n \quad (10)$$

Table VIII
Effect of Size and Shape on the Center Cooling when Steels are Cooled in Various Media

Size, Inches	Run No.	Cooled in	S	W	Time in Minutes to Cool from 875 Degrees Cent. to						200 "X," Minutes		
					850	800	700	600	500	400	300	250	
Spheres													
3/4	1229	Water	8	0.021	0.028	0.039	0.05	0.063	0.081	0.108	0.137	0.167	0.018
1 1/8	1124	Water	4.46	0.07	0.092	0.124	0.155	0.19	0.233	0.292	0.337	0.415	0.065
1 1/2	1125	Water	3.7	0.087	0.118	0.165	0.208	0.258	0.318	0.403	0.466	0.579	0.079
1 3/4	1126	Water	3.2	0.103	0.147	0.207	0.264	0.33	0.409	0.522	0.600	0.74	0.090
2	1127	Water	2.58	0.163	0.223	0.312	0.406	0.512	0.631	0.788	0.903	1.07	0.147
2 1/4	1128	Water	2.1	0.233	0.305	0.426	0.558	0.71	0.87	1.07	1.22	1.47	0.22
2 3/4	1128	Water	2.1	0.233	0.305	0.426	0.558	0.71	0.87	1.07	1.22	1.47	0.22
3	1544	Water	1.26	0.60	0.87	1.23	1.57	1.85	2.15	2.5	2.97	3.2	0.55
Rounds													
1/2 x 2	1143	Water	9	0.015	0.022	0.033	0.045	0.058	0.075	0.100	0.137	0.167	0.013
1 1/4 x 5	1176	Water	3.6	0.095	0.14	0.192	0.242	0.293	0.348	0.413	0.460	0.563	0.083
1 1/2 x 4 1/2	393	Water	3.11	0.117	0.170	0.243	0.300	0.357	0.425	0.510	0.563	0.640	0.093
1 1/2 x 6	1170	Water	3.00	0.12	0.157	0.217	0.273	0.337	0.400	0.483	0.54	0.627	0.108
2 x 6	394	Water	2.34	0.19	0.27	0.39	0.48	0.58	0.68	0.82	0.90	0.98	0.167
Plates													
3/8 x 3/8 x 1 1/2	1081	Water	8	0.014	0.023	0.040	0.056	0.071	0.087	0.106	0.115	0.127	0.0125
3/8 x 3/8 x 1 1/2	1088	Water	8	0.018	0.029	0.046	0.063	0.078	0.095	0.114	0.127	0.142	0.016
3/8 x 3/8 x 1 1/2	1102	Water	8	0.015	0.025	0.042	0.057	0.071	0.087	0.106	0.117	0.129	0.0125
1/2 x 2	1082	Water	6	0.024	0.039	0.063	0.084	0.107	0.132	0.163	0.180	0.200	0.021
1/2 x 2 x 2	1103	Water	6	0.025	0.038	0.062	0.085	0.110	0.137	0.168	0.187	0.205	0.0233
1/2 x 2 x 2	1152	Water	6	0.028	0.048	0.075	0.099	0.125	0.155	0.193	0.222	0.243	0.025
1/2 x 2 1/4 x 2 1/4	1083	Water	5.33	0.027	0.047	0.080	0.112	0.140	0.170	0.202	0.220	0.243	0.0233
1/2 x 2 1/4 x 2 1/4	1154	Water	5.33	0.040	0.061	0.084	0.108	0.133	0.163	0.210	0.243	0.267	0.031
1 1/2 x 2 3/4 x 2 3/4	1104	Water	4.36	0.038	0.065	0.105	0.142	0.175	0.213	0.267	0.280	0.305	0.034
1 1/2 x 2 3/4 x 2 3/4	1133	Water	4.36	0.040	0.067	0.107	0.142	0.174	0.205	0.238	0.267	0.297	0.035
9/16 x 4 x 4	1100	Water	3.12	0.100	0.152	0.213	0.262	0.313	0.365	0.418	0.460	0.500	0.088
Spheres													
3/4	1217	No. 2 Oil	8	0.032	0.050	0.078	0.107	0.150	0.233	0.388	0.516	0.675	0.028
1	1215	No. 2 Oil	6	0.050	0.079	0.117	0.160	0.225	0.372	0.675	0.908	1.22	0.043
1 1/8	1265	No. 2 Oil	6	0.050	0.075	0.110	0.148	0.220	0.337	0.646	0.903	1.22	0.043
1 1/2	1221	No. 2 Oil	4.46	0.087	0.135	0.213	0.303	0.428	0.606	0.927	1.22	1.47	0.08
1 3/4	1222	No. 2 Oil	4.46	0.088	0.128	0.193	0.268	0.379	0.583	1.00	1.35	1.67	0.08
2	1201	No. 2 Oil	3.2	0.13	0.23	0.38	0.57	0.85	1.27	1.98	2.67	3.2	0.108
2 1/4	1207	No. 2 Oil	3.2	0.14	0.21	0.31	0.43	0.60	0.98	1.65	2.12	2.67	0.133
2 3/4	1211	No. 2 Oil	3.2	0.15	0.22	0.33	0.45	0.63	1.08	1.57	2.12	2.67	0.135
3	1212	No. 2 Oil	2.1	0.25	0.37	0.54	0.78	1.08	1.57	2.28	2.97	3.2	0.217
3 1/4	1543	No. 2 Oil	1.26	0.3	1.10	1.60	2.10	2.70	3.7	5.8	9.85	12.5	0.67
3 3/4	1536	No. 2 Oil	0.533	3.55	5.12	7.10	8.75	10.5	12.5	15.5	18.5	21.5	3.2

Table VIII—Continued
Effect of Size and Shape on the Center Cooling when Steels are Cooled in Various Media

Size, Inches	Run No.	Cooled in	$\frac{S}{W}$	Time in Minutes to Cool from 875 Degrees Cent. to										200 "X," Minutes
				700	600	500	400	300	250					
Rounds	34x3	No. 2 Oil	6	0.083	0.15	0.263	0.403	0.657	0.043					
	1240	No. 2 Oil	6	0.068	0.12	0.263	0.403	0.657	0.037					
	1263	No. 2 Oil	6	0.053	0.10	0.237	0.470	0.82	0.047					
	1257	No. 2 Oil	4.5	0.088	0.160	0.323	0.73	0.82	0.102					
	1244	No. 2 Oil	3.6	0.113	0.26	0.48	0.73	0.82	0.102					
Spheres	1468	Air	2.58	0.60	5.33	9.5	15.5	23.5	36.8					
	1541	Air	1.26	2.83	5.83	20.0	31.0	46.83	76.67					
	1535	Air	0.533	6.3	25.5	58.0	82.0	120.5	185.0					
	1114				40.0									
Rounds	388	Air	9	0.10	0.30	0.633	0.91	1.11	0.067					
	1239	Air	9	0.083	0.242	0.633	0.67	1.28	0.05					
	1476	Air	9	0.12	0.28	0.67	0.91	1.28	0.100					
	1540	Air	9	0.11	0.35	0.91	1.11	1.57	0.083					
	1241	Air	6	0.167	0.44	1.11	1.08	1.45	0.133					
	1248	Air	6	0.15	0.41	1.08	1.08	1.45	0.10					
	1243	Air	4.5	0.21	0.55	1.45	1.9	2.47	0.15					
	1245	Air	3.6	0.30	0.73	1.9	2.47	3.25	0.233					
	1247	Air	3.0	0.43	0.98	2.47	3.25	4.0	0.35					
	1250	Air	2.25	0.70	1.40	3.25	4.0	5.0	0.60					
	1250	Air	2.25	0.70	1.40	3.25	4.0	5.0	0.60					
Cubes	Harper ¹	Water	0.500	857	806	705	605	504	202					
	Harper ¹	Air	0.500	7.5	10.3	13.1	14.4	15.6	21.6					
	Harper ¹	Air	0.500	9.5	17.0	34.2	54.0	78.0	232.0					
	Harper ¹	Air	0.500	9.5	17.0	34.2	54.0	78.0	232.0					
Cubes	Law ¹	Water	0.333	874	822	720	617	515	206					
	Law ¹	Air	0.333	13.7	17.2	22.0	25.5	28.3	42.3					
	Law ¹	Air	0.333	13.0	17.8	23.9	29.0	35.0	61.3					
	Law ¹	Air	0.333	21.0	35.0	64.0	101.5	142.0	287					
Rounds	24x134	Air	0.183	48.3	1144	1150	154.0	250.0	358					
	24x134	Air	0.183	48.3	1144	1150	154.0	250.0	358					

¹Refer to footnotes 18, 19 and 20 of the text.

in which T is the cooling time from the quenching temperature to any lower temperature (in this report expressed in minutes).

x is the "lag" in minutes; represents the cooling time for an initial drop in temperature equal to 2 per cent of the cooling range.

y is the "time constant".

S is the surface area (in this report given in square inches).

W is the volume (in this report given in cubic inches).

n is the exponent depending only on the coolant; its numerical values are the same as in all previous equations.

With this equation the time-temperature cooling curves for the center of various sizes of the simple shapes may be derived when the steel is quenched into given coolants, provided (1), the exponent

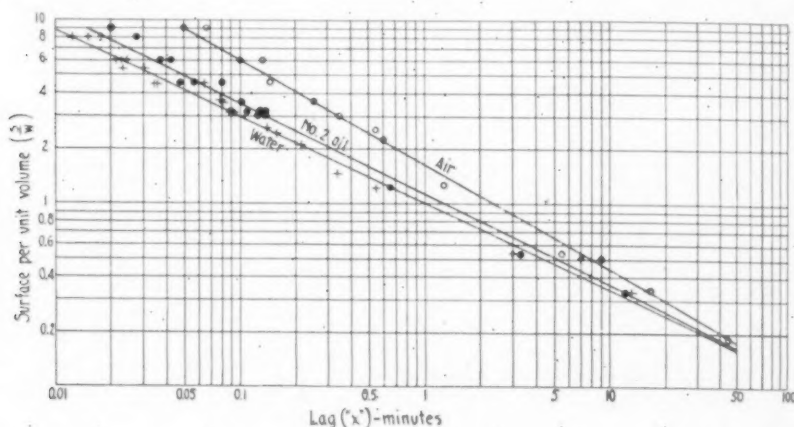


Fig. 38—Relation Between "Lag" in Center Cooling and the Surface Per Unit of Volume of Steel Samples Immersed in Water, Oil or Air. The Method of Determining "Lag" is Described in the Text.

" n " is known for the particular coolant under consideration, and (2) an accurate center cooling curve is available for some one size of one of the simple shapes when quenched from any temperature at or above about 720 degrees Cent. into this coolant. In other words, if this exponent and one good cooling curve are available, curves can be derived for the whole range of sizes and shapes quenched from temperatures at or above 720 degrees Cent.

Time-temperature cooling curves are not especially difficult to obtain, for even with so-called "drastic" coolants good results may be secured with ordinary pyrometer equipment and stop watches if the experiment is carried out with moderately large sections which reduce the center cooling velocities. The value of the exponent " n " can be determined, if it is not known, by methods already described, and when once obtained for a given coolant is fixed for the various sizes and shapes and independent of the quenching temperature.

Table IX
Values of the Time Constant "y" for Various Cooling Ranges in Various Coolants

Coolant	Time constant for cooling ranges beginning at the quenching temperature and ending at the temperature shown (expressed as % of quench-temperature) ¹								
	97.2%	91.4%	80.0%	68.6%	57.2%	45.7%	34.3%	28.6%	22.9%
Water	0.18	0.51	1.02	1.48	1.98	2.53	3.27	3.68	4.40
No. 2 Oil	0.17	0.44	1.04	1.53	2.54	3.97	6.63	9.05	...
Air	0.44	3.04	9.19	17.92	29.25	44.82	65.57	78.22	99.82

¹For example, the range from 1000-600 degrees Cent., when quenching from 1000 degrees Cent., is given as 60 per cent. (Refer to footnote 17 of the text.)

There then remain for evaluation the "lag," x , and the "time-constant," y , before the time, T , from the quenching temperature to any lower temperature can be directly determined from equation (10).

A study of the "lag," x , in cooling curves taken when cooling a wide variety of sizes and shapes in water, No. 2 oil or air shows that, in any one coolant, this increases with decrease in the surface per unit of volume; it was greater for a given surface per unit of volume when cooling in air than when quenching in oil and, likewise, greater in oil than in the more "drastic" water quench. As is indicated in Fig. 38, in which is shown the relation between "lag" and surface per unit of volume, the differences between water, the oil and air diminish as the size of sample increases (as the surface per unit of volume decreases). This feature again confirms the view, already expressed, that the center cooling of large masses is affected to a much smaller degree by the coolant than that of small sections, because the surface is far removed from the center and is small in comparison with the volume of metal to be cooled.

No attempt was made to express mathematically the relations between the "lag," the surface, per unit of volume and the coolant, for it was not difficult to prepare a chart from which the values of the "lag" could be secured. This "lag" chart is reproduced in Fig. 39, and for the sake of reducing its size semi-logarithmic co-ordinates were used.

The "lag" for any size of the simple shapes may be found in ordinary coolants by locating the intersection of the line representing the exponent " n " for the coolant with the curve for the surface per unit of volume equal to that of the sample in question. This chart is based on the lines drawn through the "scatter" of points for water, the oil and air in Fig. 38. Each of the lines representing surface per unit of volume in Fig. 39 are therefore based on three points, those

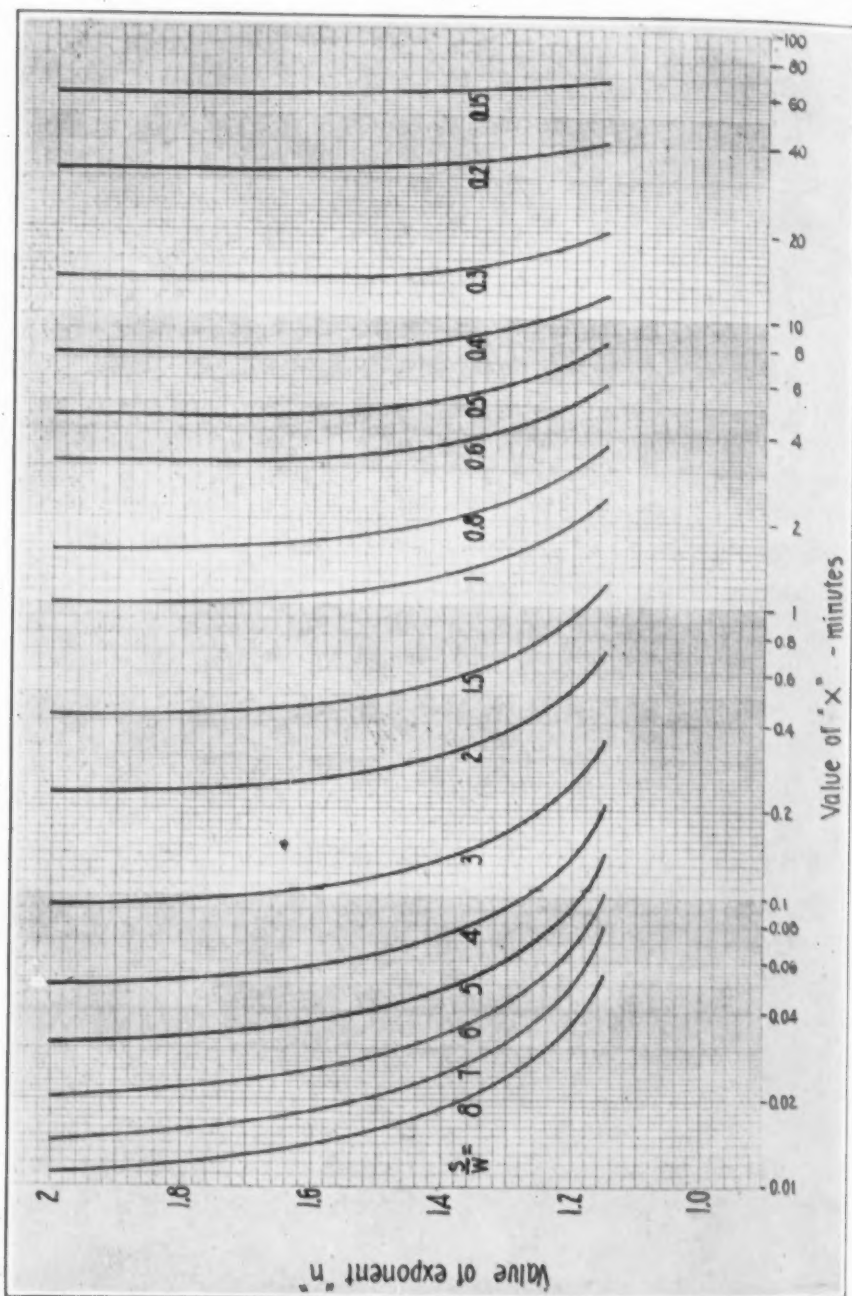


Fig. 39—"Lag" at the Center of Various Sizes and Shapes When Quenched Into Various Coolants.

From This Chart the Value of x in Equation (5) May be Determined for Various Coolants and Different Sizes and Shapes of Steel. The Value of the "Lag," x , May be Scaled Directly in Minutes if the Exponent, n , in Equation (10) is Known for the Coolant Considered.

respectively for water ($n=1.75$), the oil ($n=1.4$) and air ($n=1.15$). Their exact curvature has, therefore, not been obtained,

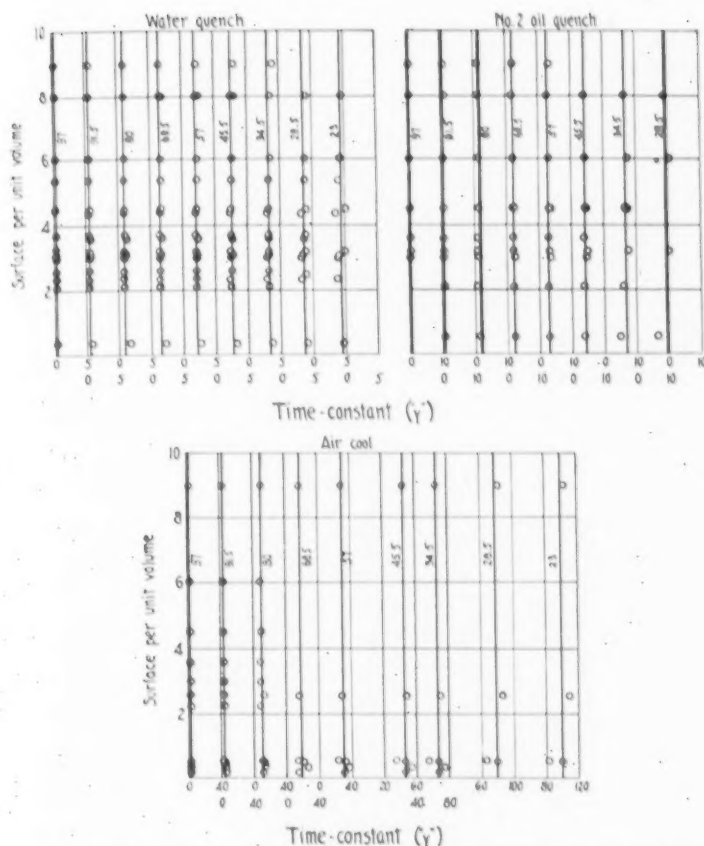


Fig. 40—Relation Between the "Time-Constant," τ , for Various Cooling Ranges and the Surface Per Unit of Volume of the Sample. Numerical Values on Each Vertical γ -line Represent the Cooling Range from the Quenching Temperature to a Lower Temperature Expressed as a Per Cent of the Temperature of Quench. (Refer to Footnote 17 of the Text.)

but probably the curves are close to proper form because with very slow cooling ($n =$ approximately 1) the lag would be large, so that each of the curves must bend sharply in the direction shown. However, the principles involved in the preparation of this chart are considered of more importance than the numerical values, which will change for different metals.

Since x of equation (10) is now known for ordinary coolants, for which the value of the exponent "n" is available, only the "time-constant," y , must be secured. The solution of equation (10) for y , based on experiments with a variety of sizes and shapes, showed that the "time-constant" (Fig. 40) was dependent only upon the cooling interval, provided the final temperature was expressed as a proportion of the initial (quenching) temperature. Average values for y are given in Table IX. The direct application of equation (10)

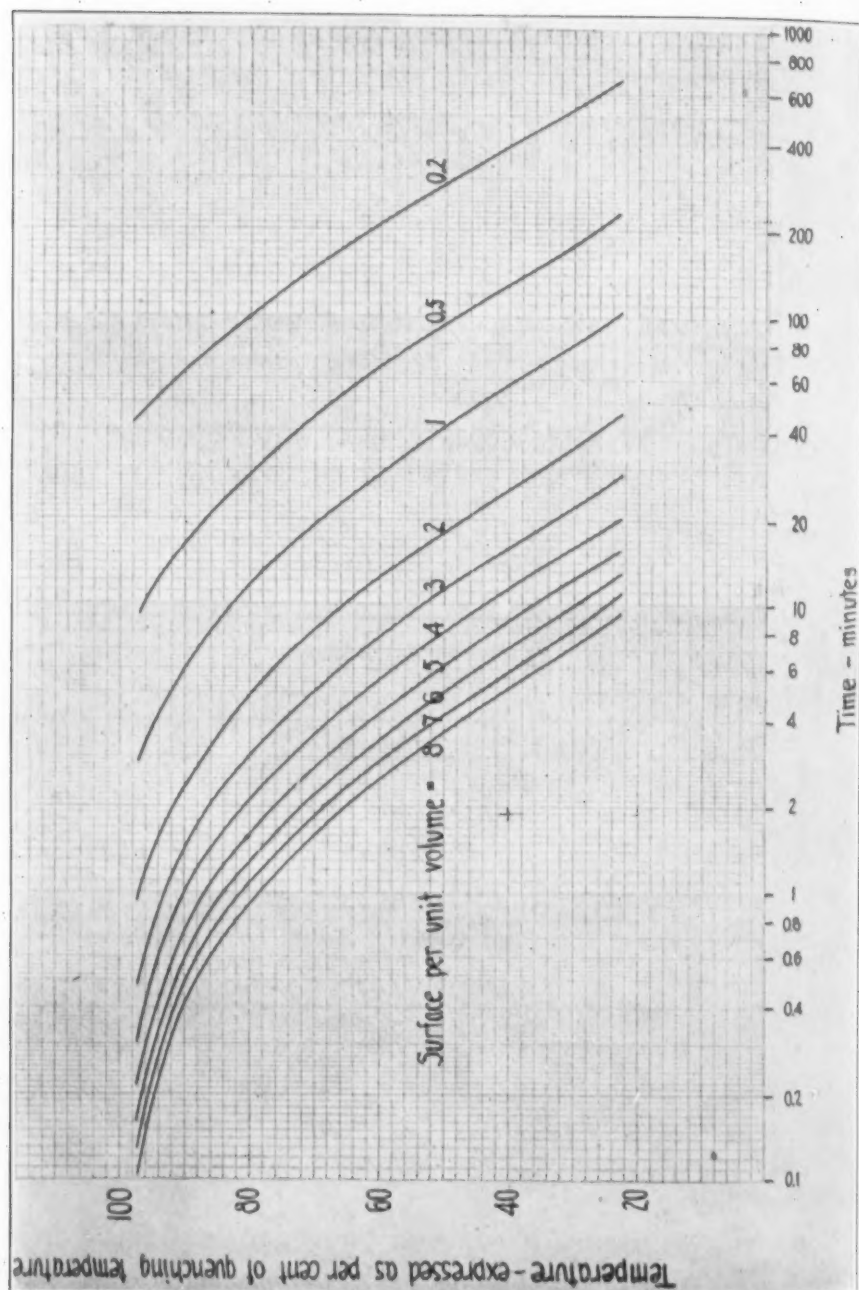


Fig. 41.—Derived Time-Temperature Cooling Curves for the Center of Different Sizes and Shapes Cooled in Air.

Semi-Logarithmic Coordinates Were Used to Reduce the Size of This Chart. Note That the Sizes and Shapes are Indicated by the Values of Surface per Unit of Volume and That All Temperatures Are Expressed as a Proportion of the Quenching Temperature. (Refer to Footnote 17 of the Text.)

may now be considered as all terms except the time T have been evaluated.

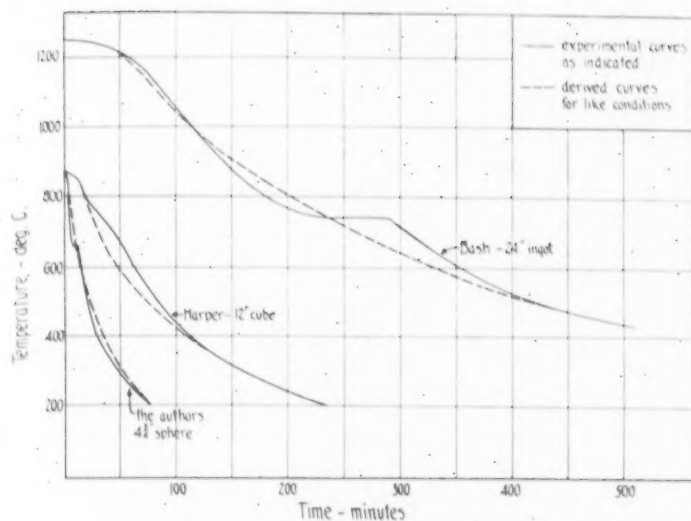


Fig. 42—Comparisons of Derived and Experimental Air Cooling Curves for the Center of Various Sizes and Shapes.

For example, consider motionless water at 20 degrees Cent. for which the value of the exponent " n " equals 1.75. If a time-temperature cooling curve is available for a sample with a surface per unit of volume of 1 when quenched from, say 875 degrees Cent., the following procedure is used in the derivation of cooling curves for other sizes and shapes quenched from temperatures at or above about 720 degrees Cent.

First, determine from the known cooling curve the lag (x) and solve the equation (10) for the time constant, y , for various cooling ranges, for example, from the quenching temperature of 875° to 800°, from 875° to 700°, from 875° to 600 degrees Cent., etc.

The values of y obtained for each interval apply to the various sizes and shapes which may be considered.

Secondly, determine from the "lag" chart, Fig. 39, the values of x for the various sizes and shapes for which data are desired. These values are obtained from the intersection of the line $n = 1.75$ with the respective surfaces per unit of volume of the sizes and shapes to be considered.

Third, to locate the cooling curve, substitute in equation (10) the proper value of x for the size considered, the proper value of surface per unit of volume and the value of y for each of the cooling intervals desired and solve in each case for the cooling time T .

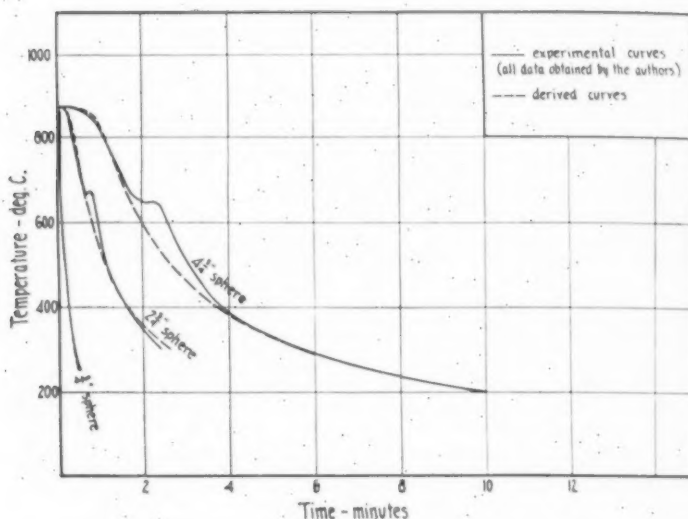


Fig. 43—Comparisons of Derived and Experimental Oil Cooling Curves for the Center of Various Sizes and Shapes. No. 2 Oil Was Used in These Experiments.

If these values of T are plotted against the final temperature expressed as a proportion of the cooling range, a time-temperature cooling curve will be obtained which will represent the cooling of the particular size and shape considered when quenched from any temperature at or above about 720 degrees Cent.

If this process is repeated for various values of surface per unit of volume, a series of cooling curves will be obtained for the various sizes and shapes quenched in this coolant.

The results of computations carried out for air in a manner similar to that described above gave the typical results shown in Fig. 41. This chart, which has been plotted to logarithmic coordinates to reduce its size, is not presented so much to give numerical values as to demonstrate the method of preparation which may be applied to many coolants. It is to be understood that the term coolant here refers to a medium at a particular temperature with a particular rate of circulation or motion; a change in any one of these or other important factors represents a change in the coolant.

c. Application of the Computations

The described relations are empirical, for they are not based on the fundamental constants of materials, but upon direct experimental determination of cooling times under a variety of conditions. The

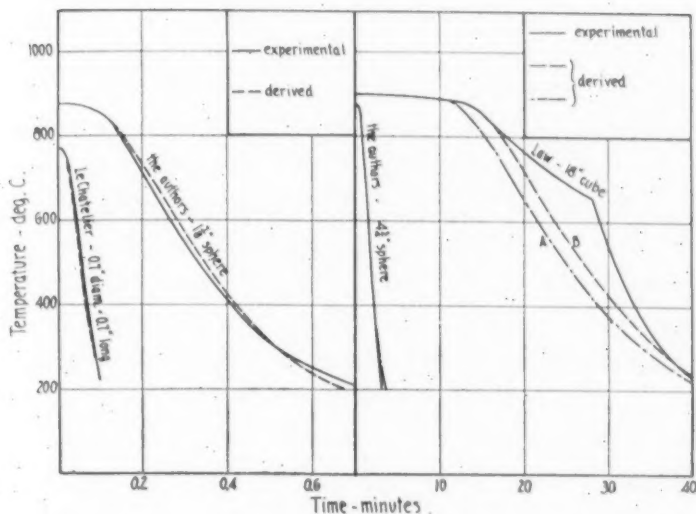


Fig. 44—Comparisons of Derived and Experimental Water Cooling Curves for the Center of Various Sizes and Shapes. LeChatelier's Cooling Curve Obtained from Rev. Met. Mem. 65, Part 1, 1904, pp. 473-493.

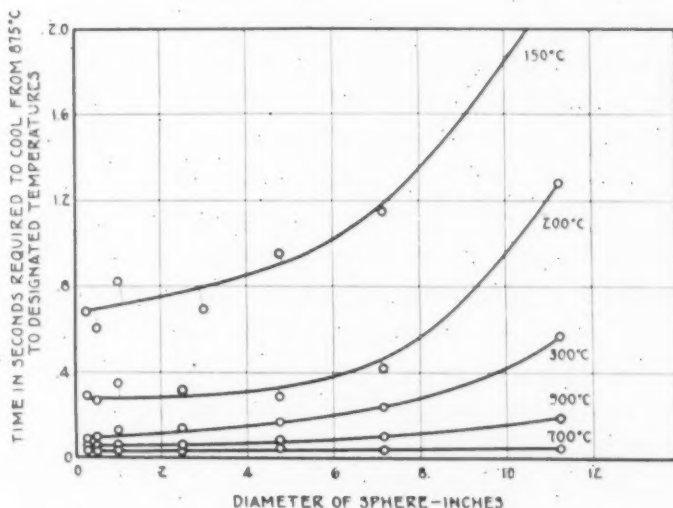


Fig. 45—Cooling Times for Different Temperature Ranges at the Surface of Spheres of Different Diameters When Quenched Into 5 Per Cent Sodium Hydroxide. Coolant Motion About 3 Feet Per Second. Coolant Initially at 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

accuracy of computations for different coolants depends upon the accuracy attained in the experiments upon which the computations are based. For this reason, it would be unwise, under ordinary conditions, to base calculations for a given coolant on a single cooling curve. A safer course would be to secure curves for at least two

widely different sizes and shapes and in both cases to demand at least two consistent experiments.

However, with accurate data from which to make computations, cooling curves should be obtained which should be more nearly representative of the actual cooling than curves derived, at this time, from purely theoretical considerations, since the latter require assumptions of the values of certain physical constants which are not now accurately known.

Comparisons of computed curves with those determined experimentally on different sizes and shapes cooled in water, No. 2 oil or air are given in Figs. 42, 43, and 44. As far as was practicable these comparisons were made with the results secured experimentally by other investigators and show that direct experimental confirmation is available for the described empirical relations covering a wide range in conditions. Naturally the derived values do not closely check all published results for supposedly similar quenching conditions, but agreement is obtained with representative experimental data from different sources.

As is shown in Figs. 42, 43, and 44, there may be appreciable variations between the derived and experimental cooling curves in the zones of thermal effects of transformations. These thermal effects can be taken into account in determining the time-constants for different coolants to secure close approximation of the cooling throughout the entire cooling range, particularly for large masses. This was not done because the magnitude and position of the transformations vary with different steels, and, as has already been stated, there were differences in the composition of the steels from which the large and small specimens were prepared. The important feature is the similarity, in given coolants, between the center cooling for various sizes and shapes, which enables a resolution of cooling curves into two major components, both related to the surface per unit of volume of the sample: (1) an initial period called "lag," which was taken as the time to produce a temperature drop of 2 per cent of the cooling range, and (2) thereafter the typical time-temperature changes characteristic of the particular coolant.

Attention should be called to Law's water cooling curve for an 18-inch cube in Fig. 44. The derived cooling curve for such a cube, based on the average "lag" from Fig. 38, is shown by the dotted line A in Fig. 44, which is generally parallel to, but offset from, the ex-

perimental curve given by Law. In other words, the major difference between the two is due entirely to the initial period or how soon after immersion in the water an appreciable center cooling begins. Comparison of Law's water cooling and oil cooling curves for the same cube shows the "lag" to be greater in water than in the less "drastic" oil quench. There is reason to believe that this is not representative of the two coolants but associated with the way in which Law's samples were quenched. If the actual "lag" scaled from Law's curve is used in place of the average lag for this size of cube given in Fig. 38, the dotted line B in Fig. 44 is obtained and closely agrees with the experimental values.

Attention is called to the fact that the values of the exponent "n" of equation (10) are the same as those in equation (7) giving the relations between surface per unit volume and cooling velocity. At least indirectly this confirms the correctness of the described data.

Another feature of interest is in the relation between the exponent, "n" and the "lag." Were it not for the fact that it was impracticable to attain the desired degree of accuracy in the experimental work, the value of "n" for different coolants might be determined directly from Fig. 39, after measuring the lag in the manner described when cooling some one size of one of the simple shapes in those coolants.

Aside from the determination of cooling times in typical coolants, the methods outlined make possible a correlation of data, irrespective of size of the simple shapes or of quenching temperatures above about 720 degrees Cent.

8. SURFACE COOLING OF SPHERES

The cooling at the surface of spheres of different diameters in water, 5 per cent sodium hydroxide, No. 2 oil and air is shown in Tables X to XIII inclusive. Several experiments were made for each size in each of the coolants and subsequent comments relate largely to the average values. However, these should be used only for general comparisons since in many cases there were appreciable variations in the individual results. Furthermore, the quenching conditions were not exactly the same for all of the spheres. Sizes up to and including $2\frac{1}{2}$ inches in diameter were quenched with the equipment illustrated in Fig. 4, in which the motion of the coolant was

Table X
Time Required for the Surface of Steel Spheres of Different Sizes to Cool to Different
Temperatures when Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) in
5 Per Cent NaOH at 20 Degrees Cent. Moving at 3 Feet per Second¹

Size, inches	Test Number	700°C.	600°C.	Time in Seconds to Cool to					
		500°C.	400°C.	300°C.	250°C.	200°C.	150°C.		
$\frac{1}{4}$	1901	.025	.030	.033	.040	.06	.10	.21	1.05
	1902	.025	.040	.050	.063	.12	.23	.42	.67
	1903	.030	.040	.045	.050	.09	.13	.23	.36
	Average	.027	.037	.043	.051	.09	.15	.29	.69
$\frac{1}{2}$	1904	.035	.040	.050	.055	.07	.11	.15	.43
	1905	.035	.038	.046	.060	.09	.13	.22	.49
	1945	.032	.050	.073	.090	.11	.14	.32	.92
	1949	.016	.043	.060	.085	.17	.24	.35	.65
	1950	.020	.040	.060	.077	.10	.15	.26	.53
	Average	.028	.042	.058	.073	.11	.15	.26	.60
1	1896	.035	.040	.045	.060	.08	.10	.15	.40
	1897	.050	.060	.080	.085	.11	.19	.40	1.20
	1947	.028	.040	.045	.064	.14	.21	.34	.71
	1948	.020	.030	.050	.086	.19	.32	.52	.99
	Average	.033	.042	.055	.074	.13	.21	.35	.82
$2\frac{1}{2}$	1899	.025	.040	.060	.065	.08	.10	.29	.65
	1900	.020	.030	.040	.050	.07	.13	.25	.80
	1951	.030	.043	.070	.100	.15	.20	.31	.52
	1952	.020	.040	.075	.120	.19	.23	.35	.84
	1953	.020	.043	.080	.130	.21	.28	.39	.66
	Average	.023	.039	.065	.093	.14	.19	.32	.69
$4\frac{3}{4}$	1981	.040	.070	.11	.13	.15	.17	.28	1.60
	1982	.050	.065	.08	.12	.19	.24	.35	1.10
	1983	.040	.062	.09	.12	.18	.23	.32	.78
	1984	.042	.065	.08	.11	.15	.18	.22	.31
	Average	.043	.066	.09	.12	.17	.21	.29	.95
7.15	1985	.030	.060	.10	.13	.22	.34	.47	1.90
	1986	.050	.090	.12	.16	.27	.33	.44	.94
	1987	.040	.060	.09	.12	.24	.27	.35	.60
	Average	.040	.070	.10	.14	.24	.31	.42	1.15
$11\frac{1}{4}$	1988	.055	.12	.18	.32	.60	.98	1.51	2.66
	1990	.030	.11	.21	.33	.54	.73	1.04	1.70
	Average	.043	.12	.19	.33	.57	.86	1.28	2.18

¹Heat effects of transformations disregarded.

produced by the rotation of the container; spheres of larger diameters were heated in larger furnaces and quenched in liquids in stationary tanks. In these cases, flow of the coolant past the specimen was obtained by moving the specimen by hand in the bath.

These two methods produced similar but by no means identical conditions at the surfaces of the spheres. Differences probably also existed in the quenching of the small spheres ($\frac{1}{4}$ inch to $2\frac{1}{2}$ inches in diameter) even though all these were handled with the one equipment. With a given velocity of coolant, the flow around a sphere $\frac{1}{4}$ inch in diameter will differ from that around a sphere of much larger diameter.

Also the disturbances momentarily produced by the introduction

Table XI

Time Required for the Surface of Steel Spheres of Different Sizes to Cool to Different Temperatures when Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) in Water at 20 Degrees Cent. Moving at 3 Feet per Second¹

inches	Number	700°C.	600°C.	500°C.	400°C.	350°C.	300°C.	250°C.	200°C.	150°C.
1/4	1881	.05	.06	.07	.08	.09	.10	.12	.16	.23
	1883	.05	.06	.07	.11	.13	.16	.19	.23	.30
	Average	.05	.06	.07	.10	.11	.13	.16	.20	.27
3/8	1827	.07	.10	.11	.13	.14	.14	.19	.31	.65
	1828	.03	.07	.12	.18	.21	.25	.32	.43	.58
	1890	.09	.10	.11	.13	.13	.17	.28	.65	..
	Average	.06	.09	.11	.15	.16	.19	.26	.46	.62
1	1823	.06	.10	.12	.15	.17	.22	.34	.58	1.08
	1824	.05	.06	.08	.12	.15	.19	.28	.43	.85
	1888	.06	.07	.07	.08	.11	.14	.19	.27	.55
	Average	.06	.08	.09	.12	.14	.18	.27	.43	.83
2 1/2	1819	.04	.08	.16	.31	.50	.77	1.18	1.82	2.80
	1820	.03	.05	.08	.10	.13	.17	.27	.42	.68
	1821	.02	.03	.05	.07	.10	.13	.17	.32	.80
	1854	.04	.07	.10	.18	.30	.50	.77	1.23	2.26
	1856	.02	.03	.05	.10	.13	.16	.26	.47	.88
	Average	.03	.05	.09	.15	.23	.35	.53	.85	1.48
4 1/4	1873	.05	.06	.13	.20	.29	.44	.66	1.11	3.10
	1874	.07	.10	.16	.23	.28	.34	.56	1.20	5.00
	Average	.06	.08	.15	.22	.29	.39	.51	1.16	4.05
7 1/2	1864	.11	.22	.39	.60	.75	.95	1.28	2.01	3.75
	1869	.07	.12	.17	.25	.30	.60	.92	4.75	...
	1872	.07	.12	.17	.25	.30	.60	.97	1.72	3.40
	1875	.08	.18	.33	.65	1.08	1.90	3.10	5.00	8.40
	1876	.08	.18	.30	.50	.75	1.30	2.20	5.00	...
	Average	.08	.16	.27	.45	.64	1.07	1.69	3.70	5.18
11 1/4	1877	.10	.28	.57	1.23	2.03	6.10	9.50	17.5	26.4
	1880	.10	.15	.25	.40	.70	3.40	10.0	22.0	...
	Average	.10	.22	.41	.82	1.37	4.75	9.75	19.8	26.4

¹Heat effects of transformations disregarded.

of the specimen into the bath would be a function of the size, the character of the surface and the manner of introduction.²¹ Variations in these factors can be expected to modify at least the initial stages of cooling at the surface of the metal and indicate that difficulties would be encountered in securing exactly comparable quenching conditions for a wide range of sizes. However, the conditions of the experiments represented those which would be encountered in good commercial heat treatment and at least should show the direction and order of magnitude of the effects of changing size.

a. Cooling Times

A graphical summary of the effects of size upon the surface cool-

²¹G. E. Bell: On the Impact of a Solid Sphere with a Fluid Surface and the Influence of Surface Tension, Surface Layers, and Viscosity on the Phenomenon. *Philosophical Magazine*, 6 Series, Vol. 48, 1924, p. 753.

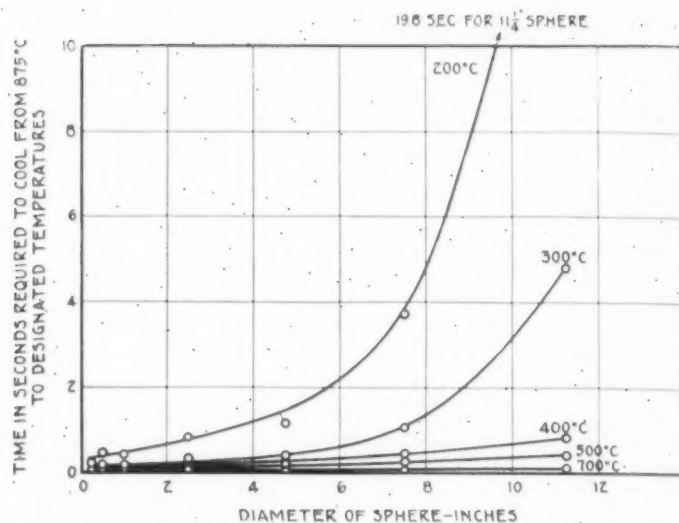


Fig. 46—Cooling Times for Different Temperature Ranges at the Surface of Spheres of Different Diameters When Quenched Into Water. Coolant Motion About 3 Feet Per Second. Coolant Initially at 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

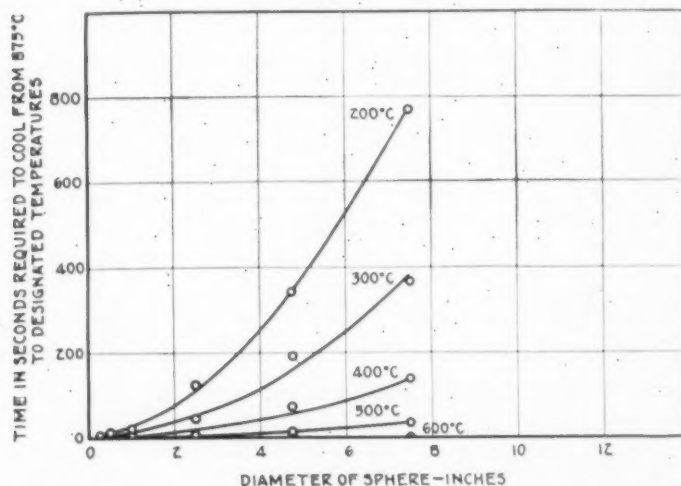


Fig. 47—Cooling Times for Different Temperature Ranges at the Surface of Spheres of Different Diameters When Quenched Into No. 2 Oil. Coolant Motion About 3 Feet Per Second. Coolant Initially at 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

ing of spheres immersed in different coolants is given in Figs. 45 to 48 inclusive. Except in the case of air cooling, increase in size produced relatively small increases in the time required for the temperature to drop from 875 degrees Cent. (1605 degrees Fahr.) to around 600 degrees Cent. (1110 degrees Fahr.). In other words the initial portions of the surface cooling curves are very nearly

the same for the spheres of different diameters when quenched in 5 per cent sodium hydroxide, water, or the oil. This is to be expected, since for a short time, the only part of the sphere which is falling appreciably in temperature is an outer layer, the thickness of which is small in comparison with the radius. Furthermore, the conditions of circulation of these coolants were not exactly the same in the early and late stages of cooling since the specimen was being

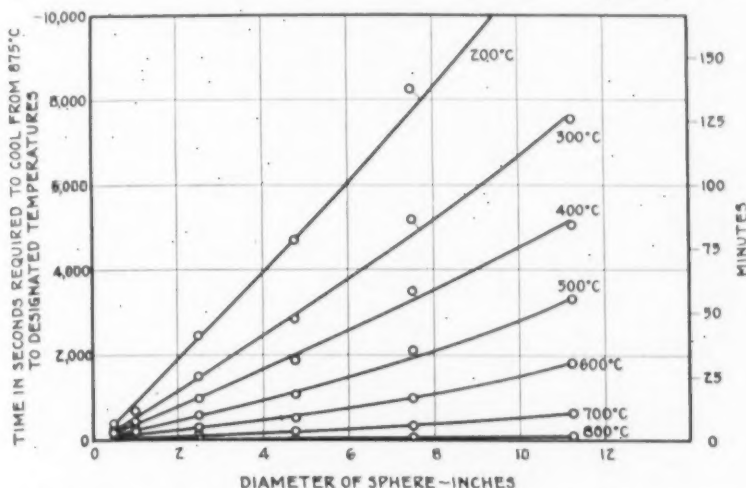


Fig. 48—Cooling Times for Different Temperature Ranges at the Surface of Spheres of Different Diameters When Cooled in Still Air at Atmospheric Temperatures.

lowered rapidly within the bath for a short period subsequent to immersion. The differences observed under these conditions may, therefore, be considerably smaller than would have been observed if the rapid motion of the specimen relative to the coolant during immersion could have been avoided.

Much larger differences are produced by variations in the sphere diameter when larger cooling intervals are considered, such as 875 to 200 or 300 degrees Cent. (1605 to 390 or 570 degrees Fahr.). In such cases, there was a definite increase in the time required for the surface to reach a selected temperature as the sphere diameter increased. However, large differences in cooling times were observed only in the large specimens comprising spheres $4\frac{3}{4}$ inches or more in diameter.

An unexpected effect was observed in water quenching. As is shown in Table X, the average cooling of the surface from 875 degrees Cent. (1605 degrees Fahr.) to about 600 degrees Cent. (1110 degrees Fahr.) was more rapid in the $2\frac{1}{2}$ -inch spheres than

Table XII
Time Required for the Surface of Steel Spheres of Different Sizes to Cool to Different
Temperatures when Quenched from 875 Degrees Cent. (1605 Degrees Fahr.) in
No. 2 Oil at 20 Degrees Cent. Moving at 3 Feet per Second¹

Size, inches	Test Number	800°C.	700°C.	600°C.	500°C.	400°C.	300°C.	250°C.	200°C.
$\frac{1}{4}$	1886	.03	.14	.37	.76	1.27	2.28	3.00	4.10
	1887	.03	.14	.32	.62	1.18	2.40	3.15	4.30
	1915	.03	.14	.32	.65	1.45	2.68	3.55	4.70
	1916	.03	.14	.35	.82	1.62	2.75	3.65	5.10
	Average	.03	.14	.34	.71	1.38	2.53	3.34	4.60
$\frac{1}{2}$	1867	.04	.13	.30	.90	2.03	3.95	5.56	7.9
	1868	.04	.13	.35	1.00	2.18	4.05	5.60	8.2
	Average	.04	.13	.33	.95	2.11	4.00	5.58	8.1
1	1878	.03	.12	.30	.80	2.60	7.0	11.5	19.5
	1879	.04	.15	.32	1.15	4.45	9.9	13.0	20.2
	1919	.04	.18	.55	1.75	3.50	8.0	14.0	22.6
	Average	.04	.15	.39	1.23	3.52	8.3	12.8	20.8
2 $\frac{1}{2}$	1871	.08	.26	1.10	4.0	9.3	52	86	133
	1923	.05	.25	1.10	3.2	9.2	63	98	144
	1924	.06	.20	1.50	4.8	11.2	63	101	143
	1926	.03	.15	.80	2.7	7.5	24	70	116
	1927	.05	.15	.60	2.5	7.0	24	45	90
	Average	.05	.20	1.02	3.4	8.8	45	80	125
4 $\frac{3}{4}$	1890	.12	.31	1.5	7.6	50	203	277	367
	1894	.04		3.5	13.3	72	179	248	312
	1895	.04	.30	1.8	7.0	67	177	244	324
	1910	.03	.20	.6	9.0	73	179	256	335
	1979	.09	.42	3.9	32.0	103	227	285	375
	Average	.06	.31	2.4	14.3	73	193	262	343
7 $\frac{1}{2}$	1976	.06	.20	1.4	50	145	363	560	775
	1977	.11	.36	2.4	24	130	370	550	750
Average		.09	.28	1.9	37	138	366	555	768

¹Heat effects of transformations disregarded.

in the 1-inch spheres and likewise more rapid in the 1-inch spheres than in the $\frac{1}{2}$ -inch spheres. It is difficult to reproduce results in these small specimens, for reasons already discussed, but these effects were observed so consistently upon repeating the experiments that they probably have some significance.

An observation made by Heindlhofer²² tends to support the view that these effects are real and not solely the result of imperfect control of the conditions of quenching. Heindlhofer calculated the values of surface emissivity from center cooling curves of two silver cylinders, respectively, 2 centimeters and 0.6 centimeters in diameter. These values were much larger for the larger cylinder. He concluded that the specific surface emission²³ "seems also to depend on the absolute size of the quenched object, smaller

²²K. Heindlhofer: Quenching: A Mathematical Study of Various Hypotheses on Rapid Cooling, *Physics Review*, 2 series, Vol. 20, 1922, p. 221.

²³Loss of heat at surface in calories per second, per square centimeter of surface, per degree difference in temperature of surface and coolant.

Table XIII

Time Required for the Surface of Steel Spheres of Different Sizes to Cool to Different Temperatures when Cooled from 875 Degrees Cent. (1605 Degrees Fahr.) in Still Air at Room Temperature¹

Size, inches	Test Number	800°C.	700°C.	Time in Seconds to Cool to				
				600°C.	500°C.	400°C.	300°C.	200°C.
1/2	1656	7	23	51	93	148	227	396
	1718	7	23	46	85	133	203	360
	Average	7	23	49	89	141	215	378
1	2008	12	42	100	190	307	452	695
	2009	12	46	107	197	307	444	685
	Average	12	44	104	194	307	448	690
2 1/2	1649	32	116	290	590	995	1540	2650
	1720	40	137	320	635	1095	1585	2415
	1736	37	135	315	605	985	1500	2500
	1740	35	122	307	595	945	1430	2230
	Average	36	128	308	606	1005	1514	2449
4 1/4	1651	50	225	535	1125	1950	2830	4700
	1745	50	225	510	1035	1835	2890	4700
	Average	50	225	523	1080	1893	2860	4700
7 1/2	1754	70	360	1020	2120	3520	5140	8200
	1755	70	360	980	2060	3460	5230	8320
	Average	70	360	1000	2090	3490	5185	8260
11 1/4	1743	75	600	1740	3240	5040	7440	12000
	1749	75	660	1860	3360	5040	7620	12360
	Average	75	630	1800	3300	5040	7530	12180

¹Heat effects of transformations disregarded.

sizes having smaller specific emission. This would point to a difficulty in obtaining very great quenching speeds by trying to reduce the diameter of the quenched specimen."

b. Cooling Rates

Since the hardening of steels is related to the rates at which the metal is brought through the transformations, it is of interest to examine the cooling rates at the surface of the spheres.

The most rapid surface cooling, at temperatures around 700 degrees Cent. (1290 degrees Fahr.), was observed when quenching in 5 per cent sodium hydroxide. The rates of cooling varied from about 12,000 to 3000 degrees Cent. per second for spheres from 1/4 to 11 1/4 inches in diameter.

When quenching in water, with the moderate circulation used in all the experiments (approximately 3 feet per second), the cooling rates at temperatures in the neighborhood of 700 degrees Cent. varied from around 8000 to 1000 degrees Cent. per second in spheres from 1/2 to 11 1/4 inches in diameter. However, the surface did not drop instantaneously to the coolant temperature as is assumed in

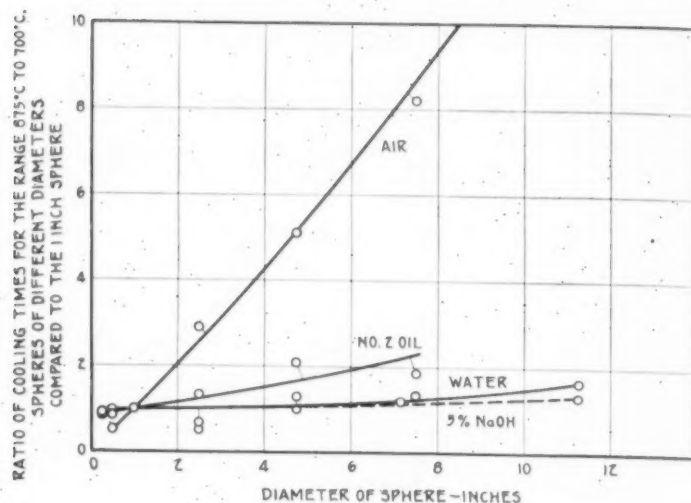


Fig. 49—Effect of Sphere Diameter on the Surface Cooling Times for the Range 875 to 700 Degrees Cent. (1605 to 1290 Degrees Fahr.) When Cooling in Different Media. Chart Based on Data in Figs. 23 to 26 Inclusive.

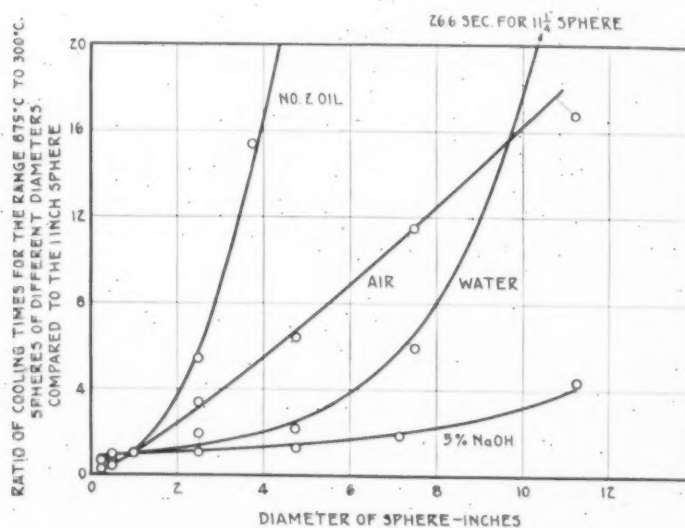


Fig. 50—Effect of Sphere Diameter on the Surface Cooling Times for the Range 875 to 300 Degrees Cent. (1605 to 570 Degrees Fahr.) When Cooling in Different Media. Chart Based on Data in Figs. 23 to 26 Inclusive.

some theoretical derivations of cooling curves. This condition was approached more nearly when quenching in 5 per cent sodium hydroxide.

As is shown in Figs. 23 and 24, the first rapid cooling in either water or 5 per cent sodium hydroxide did not continue to coolant temperatures. Instead there was an abrupt change in the slope

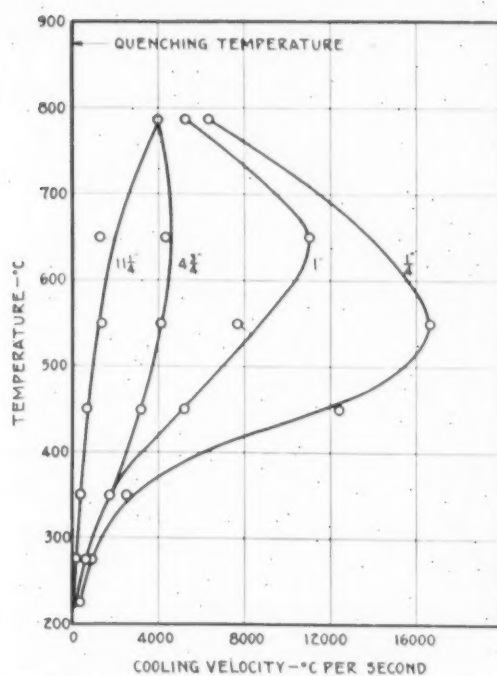


Fig. 51—Effect of Sphere Diameter on the Relation Between Surface Temperature and Cooling Velocity in 5 Per Cent Sodium Hydroxide. Coolant Motion About 3 Feet Per Second. Coolant Temperature 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

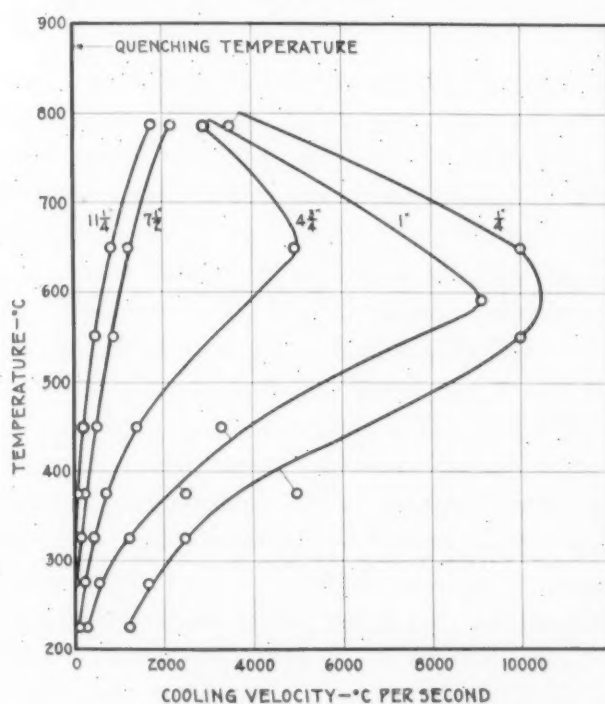


Fig. 52—Effect of Sphere Diameter on the Relation Between Surface Temperature and Cooling Velocity in Water. Coolant Motion About 3 Feet Per Second. Coolant Temperature 18 to 22 Degrees Cent. (65 to 70 Degrees Fahr.).

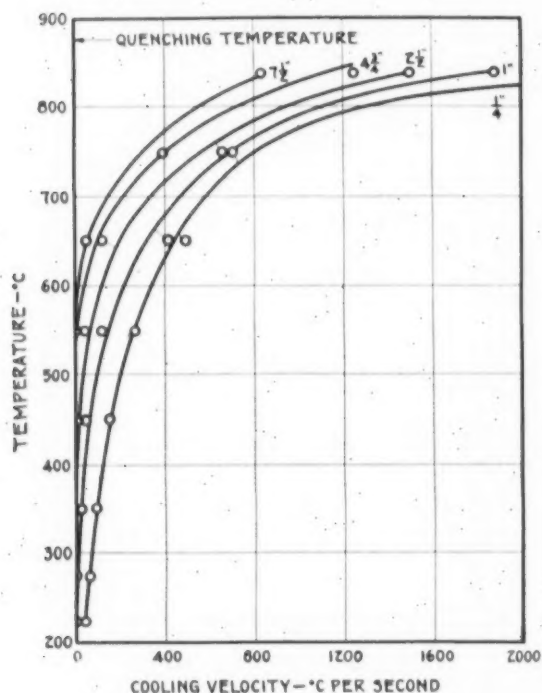


Fig. 53—Effect of Sphere Diameter on the Relation Between Surface Temperature and Cooling Velocity in No. 2 Oil. Coolant Motion About 3 Feet Per Second. Coolant Temperature 18 to 22 Degrees Cent. (65. to 70 Degrees Fahr.).

of the cooling curves at temperatures well above the boiling point of water. The temperatures at which this change occurred increased with increase in the diameter of the sphere and were higher in water quenching than in quenching in 5 per cent sodium hydroxide.

Similar characteristics were shown in oil quenching although here the rates of temperature change at the surface were lower than in the aqueous solutions, and the change from relatively rapid cooling to slow cooling was less abrupt and occurred at somewhat higher temperatures, in the neighborhood of 500 degrees Cent. (930 degrees Fahr.).

These results throw some doubt on the accuracy of calculations based on the assumption of instantaneous cooling of the surface to coolant temperatures. It would be more reasonable to assume instantaneous cooling to some higher temperature even for such rapid coolants as the 5 per cent sodium hydroxide solution. But as is shown by the results of the experiments this temperature varied with the size of the piece.

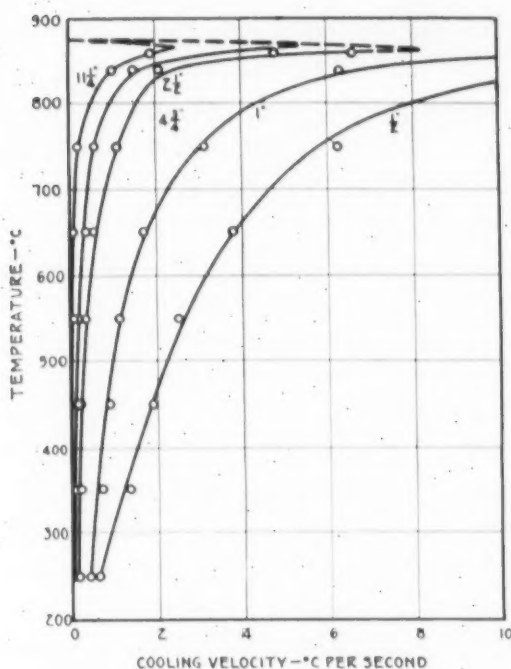


Fig. 54—Effect of Sphere Diameter on the Relation Between Surface Temperature and Cooling Velocity in Still Air at About 20 Degrees Cent. (65 Degrees Fahr.).

c. Comparison of the Coolants in Relation to Size of Sphere

The rates of cooling in the temperature range around 700 degrees Cent. (1290 degrees Fahr.) are of particular interest since it is in this range of temperature that ordinary carbon steels acquire "the will to harden." It will, therefore, be of interest to examine the proportional increase in cooling times for different temperature ranges in the different media when the size of sphere is increased. Fig. 49 shows the proportional increase in cooling times for the temperature range 875 to 700 degrees Cent. (1605 to 1290 degrees Fahr.), and Fig. 50 a corresponding summary for the range 875 to 300 degrees Cent. (1605 to 570 degrees Fahr.).

For the short high temperature range the increase in cooling time with increase in diameter of sphere was much larger in the slow coolants, air and oil, than in the rapid coolants, water and 5 per cent sodium hydroxide. Fig. 49 shows that the magnitude of the effects of size decreased in order of the rapidity of the coolants.

The situation is a little different when considering the larger

cooling range, 875 to 300 degrees Cent. (1605 to 570 degrees Fahr.). Fig. 50 shows that the cooling times increased more rapidly in water than in 5 per cent sodium hydroxide or air for large increases in the diameter of sphere. However, the largest effects were found with the oil.

This means that 5 per cent sodium hydroxide can be effective in increasing the depth of hardening (or in procuring full hardening) at the surface of large masses where water fails to produce the desired effects. This is not to be interpreted to apply to all sizes but should be valid for a moderately wide range of sizes encountered in industrial work. This further involves the assumption that the circulation of the coolant is moderate and comparable in the case of the two coolants.

Such differences in surface cooling of large masses are not necessarily reflected at interior points. As was previously shown appreciable increases in size tended to reduce the differences in center cooling between water and 5 per cent sodium hydroxide.

Further information on the effects of size upon the surface cooling in the different media may be obtained from Figs. 51 to 54 inclusive. In these charts the average cooling rates for different temperature ranges are plotted against the mean temperatures of the respective ranges.

In both oil and air the maximum rates of cooling were found to be very close to the initial (quenching) temperature and the rates steadily decreased with decrease in the temperature of the surface.

In water and 5 per cent sodium hydroxide the cooling rate-temperature curves (Figs. 51 and 52) showed maximum cooling rates at different temperatures. For spheres of small diameter, around $\frac{1}{4}$ to $4\frac{3}{4}$ inches, the maximum cooling rates were found at relatively low temperatures in the neighborhood of 500 to 700 degrees Cent. (930 to 1290 degrees Fahr.). With increase in size, the temperatures of maximum cooling rates tended to approach the initial temperature so that the curves assumed a form like that of the curves for oil and air. This change occurred in smaller spheres when quenching in water than when quenching in 5 per cent sodium hydroxide.

These results are of practical interest since they indicate that no appreciable increase can be expected in the surface cooling

rates of large masses, at temperatures around 700 degrees Cent. (1290 degrees Fahr.), by raising the quenching temperature. In small pieces, immersed in water or 5 per cent sodium hydroxide, increase in the quenching temperature should be effective in increasing the rates of cooling around 700 degrees Cent. (1290 degrees Fahr.). This, of course, is based on the assumption that increase in the initial temperature will produce, at least roughly, a proportional change in the temperature at which the maximum cooling rates are observed as it did in the experiments on center cooling. Since the cooling rates at temperatures around 700 degrees Cent. (1290 degrees Fahr.) play a major part in the hardening produced in carbon steels, an increase in the quenching temperature can increase the depth of hardening in small sizes but not appreciably in large sections.

A quantitative evaluation of the effects of size on surface cooling is hardly justified since the experiments described were representative only of commercial practice and were not controlled with respect to all of the variables suspected of affecting the removal of heat at the surfaces of the specimens.

Study of the effects of the many variables which can be conceived to affect the cooling is a task of considerable magnitude and would necessitate surmounting numerous experimental difficulties. A complete survey was not attempted but in the course of the previous experiments questions arose which made it desirable to consider certain of the less generally recognized phases of the subject. And these will be considered in subsequent chapters.

Comment and Discussion

Discussion of the Paper by George Batty, on "The Production of Electric Steel For Castings"

BY P. B. PARKS²

THE writer is in strong agreement with the author that in the electric furnace process the practice of eliminating a certain amount of carbon by means of quiet boil is the better and scientifically correct method of producing sound steel either for castings or ingots. The other, or so called "crucible method," he considers fundamentally wrong. The crucible process is essentially a melting process, in which only the purest ingredients are used, and in which little further refining is necessary, and to attempt to carry out that principle in an open-hearth furnace, (to which class the ordinary electric furnace really belongs), with a charge usually consisting of miscellaneous steel scrap, cannot be considered good steel making practice. The scrap for the charge can and should be graded and to a certain extent it may be cleaned,—incidentally it is the practice here to rumble all the shop scrap and all surplus metal after casting is poured into small tapered ingot molds to keep it clean and in a convenient form for recharging,—but this does not render the charge in any way "pure" from the point of view of freedom from oxidation products, which are so carefully and completely eliminated in the crucible process. In the writer's opinion, the excuse for this "crucible method" in the electric furnace may be found in the time factor, which point neither the author, nor any of his critics seem to have mentioned, since the introduction of ore, which should not be added until,—to quote Mr. Batty,—"the melter gets a good bath of metal," must of necessity prolong the heat if sufficient time is subsequently allowed for the ore to boil down the carbon, or as it is often termed, "work through."

The writer, who has had fifteen years' experience in making steel by most of the commercial processes in Sheffield, England, was greatly surprised at the importance attached on this Continent to the actual time taken to make a heat of steel. Soon after his arrival in Canada, some sixteen months ago, he received a catalog from a firm in the States, who announced themselves as "the largest manufacturers of electric furnaces in the world," in which everyone of their steel making furnaces was actually named and described according to the number of pounds or tons of steel it was supposed to produce per hour! In the writer's opinion this kind of propaganda can do no good, but may very easily do incalculable harm to steel making as an art and a profession. A particular type of furnace may be capable of rendering a certain quantity of scrap sufficiently

¹George Batty, "The Production of Electric Steel for Castings", TRANSACTIONS, American Society for Steel Treating, Vol. 17, March 1930, p. 449.

²P. B. Parks, steel-maker and metallurgist for the Riverside Iron Works Ltd., Calgary, Alberta, Canada.

fluid in a given time, to enable it to be poured into molds, but scope for the profitable operation of such practices is fast becoming very limited.

Today the up-to-date steel manufacturer must be prepared to make his steel to definite chemical and physical specifications, which necessitates the intelligent co-operation of both the melter and the chemist. The matter of primary importance is to ensure that the metal is of correct chemical composition, and that it is in a suitable condition as regards cleanliness, soundness, and fluidity when tapped, and the question as to whether the heat is half an hour or an hour longer or shorter in the making is trivial; and when the question of expensive alloys is involved one might reasonably say that it fades into insignificance.

Whilst on the subject of alloy steels and their rapidly increasing adoption, the writer does not think that Mr. Bull need have much apprehension as to the supply of scrap for so-called common steel, since with the exception of nickel and molybdenum, all the other alloying elements will be oxidized out during melting if the oreing down method is used; against this may be argued the fact that these elements will thus be lost, but this will be offset by the lower cost of this kind of scrap which must naturally follow as soon as it becomes plentiful on the market.

The writer does not think that the addition of ferrosilicon to the bath in an acid furnace should be made a standard practice, as in his experience more often than not it is quite superfluous. If a sufficiently reducing slag is obtained towards the finishing period of the melt enough silica will be reduced from the slag to the metal to make any further silicon additions unnecessary.

Upon the subject of blowholes, the writer agrees with the author that the primary cause of this trouble can be traced to moisture in the sand, proof of which can readily be observed in green sand castings, the steel often actually rising in one head and sinking in another on the same casting. In his opinion to try and overcome this by using aluminum is bad practice, the cure generally being much worse than the disease. Unfortunately, both the average casting-floor foreman and melter have been allowed such absolute freedom in the use of aluminum that they are both loth and afraid to do without it. Also too much importance is often attached to excessive sinking of the steel in the heads. It is well known that aluminum causes increased piping, which in conjunction with excessive sinking simply means that instead of the pipe being located in the head,—its proper place,—it is forced down into the body of the casting. The writer likes to see the heads well filled and showing only a slight concavity, which condition can often be obtained by leaving the steel a little longer in the furnace under a good reducing slag and cutting down, or even cutting out altogether, the use of aluminum.

Author's Reply

With reference to the time at which ore is added to a bath, I would say that there is no prolongation of the time it takes to produce the heat by the method I advocated of adding the ore, but you should understand that when I use the words "the ore should not be added until the melter gets a good bath of metal" I mean that there is a good open pool of metal in the middle of the

furnace, unmelted material still being on the banks. Ore is best added at this time because the bath is hot enough to assimilate it and because of the intense localization of heat near the electrodes a boil will commence and proceed while there is still unmelted material on the banks of the furnace. Whilst the slag is very rich in oxide of iron, it tends to attack the acid banks if they are exposed, but by having a good deal of the boil period proceed whilst the banks are still protected by unmelted metal, we minimize the dilution of the slag by preventing, to a considerable extent, the erosion of the banks.

It is desirable to maintain slag volume at an amount which is merely sufficient to cover adequately the surface of the metal and, in my opinion, a slag in quantity equal to 6 per cent by weight of the bath is quite satisfactory in the electric furnace.

When ore has been added and the boil is proceeding, it is sound practice to add limestone in a quantity calculated to add about 8 per cent CaO to the slag, and it is also considered important that melters should not thicken up a slag merely because it happens to appear watery in the early stages of the boil. The slag is thin because of its composition and, as the elimination of carbon proceeds, the composition of the slag changes and the slag comes to good physical condition as well as good chemical condition. The practice of diluting or thickening slags with additional sand is to be deprecated because this decreases the MnO content with the result that when the final additions of ferrosilicon and ferromanganese are made to the charge excessive manganese losses to the slag are likely to occur.

The advocated practice, therefore, in respect of adding ore is to choose a time as early as possible in the heat when ore may be introduced to liquid metal and then to follow the practice which is described by the Sheffield melters as "boiling the scrap off the banks."

In steel foundries where a considerable proportion of the charge is foundry scrap of a manganese content of 0.7 to 0.8 per cent and a silicon content of 0.3 to 0.4 per cent it is quite safe to add some ore with the charge, but the ore should be so located in the charge that it does not lie in contact with the hearth.

Many melters have displayed interest in a proposition that they should attempt to estimate the amount of ore requisite to bring about the elimination of definite amounts of silicon, manganese, and carbon from the charge and I think that wherever a melter has sufficient knowledge to carry out such calculations he finds an added interest in his work by following out and checking off in practice the calculation of the theoretical values of the reactions.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,746,676, Feb. 11, 1930, 1,746,677, 1,746,678, 1,746,679, 1,746,680, Chemical Reagent, Fred H. Rhodes of Ithaca, N. Y.

These patents all relate to a particular chemical reagent or inhibitor for retarding the evolution of hydrogen at the surfaces of metals immersed in a pickling solution. The inhibiting agents are described as cyclic organic compounds of nitrogen such as quinaldine, acridine derivatives such as 3,6 dimethyl 2,7 diamino acridine, dinaphthacridine or diquinolyl. It is suggested that these chemicals will decrease the rate of the evolution of hydrogen which normally takes place. They are particularly useful in electroplating processes and eliminating the scale formed in pipes and the tubes of automobile radiators.

1,747,796, Feb. 18, 1930, Incorrodible Aluminum Alloy, Hans Schorn, of Lausitz, Germany.

This patent relates to a new aluminum alloy and particularly to an alloy which is incorrodible to a high degree and substantial proof against corrosion by sea water. This alloy includes the addition of 0.05 to 0.1 per cent of titanium to commercial aluminum. It is also suggested that the small proportion, say of, 1 to 6 per cent of magnesium should be added to make the usual commercial aluminum sea water corrosion proof.

1,748,623, Feb. 25, 1930, Method of Nitriding Steel Articles, Robert Sergeson, of Massillon, Ohio, Assignor to Central Alloy Steel Corporation, of Massillon, Ohio, a Corporation of New York.

This invention relates in general to the heat treatment of articles made from steel alloy for the purpose of placing the articles in a condition to receive thereon a hard tough coherent case or coating when the articles are subsequently nitrided as by means of ammonia gas. The method comprises heating the articles to a temperature of about 1650 degrees Fahr., quenching the articles, drawing the articles at a temperature of 1,000 degrees Fahr. and then nitriding the articles. Such treatment not only increases the case depth from an average of 0.010 to 0.001 inch, but it increases the hardness from 850 Brinell to approximately 1015 Brinell.

1,748,759, Feb. 25, 1930, Process of Making Low Carbon Ferro-Alloys, Frederick M. Becket of New York, N. Y., Assignor to Electro-Metallurgical Company, a Corporation of West Virginia.

This particular patent relates to the manufacture of rustless iron such as low carbon ferromanganese and the process outlined is to blow oxygen onto the surface of the molten iron-chromium alloy containing an excess

of carbon to raise the temperature and remove a part of the carbon and then blowing substantially pure hydrogen through the molten alloy to remove more carbon and prevent undue chromium losses. The carbon content of alloy should be below 0.2 per cent during the later part of the hydrogen blow.

1,750,270, March 11, 1930, Coated Iron and Steel Articles and Method of Making the Same, Elmer M. Jones of Detroit, Michigan, Assignor to Parker Rust-Proof Company of Detroit, Michigan, a Corporation of Michigan.

The specific invention relates to the coating of iron or steel with a silicon compound. The operation consists in preparing a water solution of acid phosphates of iron, manganese or zinc and introducing silicon in the form of sand. After boiling the solution, apparently silicon acid is formed, and as the metal articles are introduced into the bath a coating will be formed which will continue during the evolution of hydrogen bubbles. The coating is formed in situ on said surfaces and comprises insoluble phosphate of metals used and a compound of silicon. The coating is not only rust-proof, but it also serves as a very good foundation for other coatings.

1,750,651, March 18, 1930, Means of Cleaning and Protecting Metal Surfaces, James C. Vignos, of Nitro, West Virginia, Assignor to the Rubber Service Laboratories Company, of Akron, Ohio, a Corporation of Ohio.

The present invention relates particularly to a process for the pickling of iron or steel wire sheets or similar metallic objects. It is also useful for removing boiler scale. The invention discloses the use of the mercaptans which are compounds containing the C-SH group and preferably those mercaptans wherein the sulph-hydrate group is attached to a carbon atom of a thiazole group. The pickling bath comprises a sulphuric acid solution containing a small proportion of a foaming agent and a sulphonated mercaptan compound.

1,750,796, Mar. 18, 1930, Alloy and Cutting Tool Made Therefrom, Burnham E. Field, of Douglaston, New York, Assignor to Haynes Stellite Company, a Corporation of Indiana.

This patent covers an alloy consisting chiefly of tungsten, cobalt, and chromium containing upward of 35 per cent tungsten, upward of 30 per cent cobalt, a substantial proportion of chromium, but less than 12 per cent and between 12 per cent and 1.25 per cent of boron substantially free of nickel. It is noted that the tungsten should not exceed 50 per cent because the melting point would be too high and where the tungsten is approximately 40 per cent it was found that the Brinell hardness was 600. This alloy gives good results as a lathe tool for the high speed cutting of cast iron and steel.

1,729,765-6-7, Oct. 1, 1929, Cleaning of Metal Surfaces, Clarence F. Dinley, Detroit, Michigan.

A coating and drying composition for removing foreign substances

such as rust, rust stimulants, and oil from metal surfaces preparatory to painting; comprising compatible solvents for the said substances in combination with a finely divided vehicle and powdered absorptive amorphous carbon.

1,727,331, Sept. 10, 1929, Process of Coating Aluminum Electrolytically, Carl L. Beal, Rochester, New York, Assignor to Eastman Kodak Company, Rochester, New York, a corporation of New York.

In the process of electroplating an aluminum surface, the steps of treating said surface in a dilute aqueous alkaline bath without electrolysis, treating said surface as the cathode in an acid dilute aqueous bath under non-oxidizing conditions, and thereafter electrodepositing a coating upon said treated surface.

1,729,339, Sept. 24, 1929, Alloy of Magnesium, John A. Gann, Midland, Michigan, Assignor to The Dow Chemical Company, Midland, Michigan.

As a new product, an alloy containing from 90 to 95 per cent of magnesium and between 10 and 5 per cent of cadmium.

1,728,052, Sept. 10, 1929, Aluminum-Welding Rod, Henry Gilbert, Philadelphia, Pennsylvania.

A welding rod composed of substantially 88.74 per cent of aluminum, 2.42 per cent of copper, 8.06 per cent of cadmium and 0.78 per cent of bismuth.

1,731,021, Oct. 8, 1929, Bearing-Metal Alloy, Karl Müller and Wilhelm Sander, Essen, Germany.

A bearing metal alloy comprising about 70 to 75 per cent of lead, about 15 to 25 per cent of antimony, about 3 to 6 per cent of tin, about 1 to 3 per cent of a metal of the cobalt type, about 0.6 to 2 per cent of copper, and an appreciable amount not exceeding 1 per cent of metals of the iron group.

1,729,631, Oct. 1, 1929, Process of Reclaiming Scrap Metals, Theron D. Stay, Cleveland, Ohio, Assignor, By Mesne Assignments, to Aluminum Company of America, Pittsburgh, Pennsylvania.

The improved process of reclaiming light, readily oxidizable metals from finely divided scrap metal which comprises freeing the scrap metal of particles of iron, adding the scrap metal to a molten bath of metal of the kind to be reclaimed in which there are upwardly and downwardly directed currents of circulation, quickly immersing the scrap metal in the molten bath.

1,734,932, Nov. 5, 1929, Weld Rod and Method of Making the Same, James M. Weed, of Ballston Lake, New York, Assignor to the General Electric Company, of New York.

An internally fluxed weldrod of the cored type comprising a single metallic strip whose two edges engage opposite sides of a central portion thereof constituting a core with which they form a plurality of oppositely disposed seams.

THE ENGINEERING INDEX

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In the preparation of the Engineering Index by the staff of the American Society of Mechanical Engineers some 1700 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. is supplied with this selective index to those articles which deal particularly with steel treating and related subjects.

AIRPLANE ENGINE MATERIALS

METALS. Metallurgy Encounters New Problems, L. M. Jordan. *Heat Treating and Forging*, vol. 16, no. 1, Jan. 1930, pp. 75-76 and 131.

Automotive and aircraft motors call for superior materials, treatments and designs; contribution of metallurgists to needs of aviation; failure of parts of engine; only by exhaustive investigation can infallible factor of safety, applied on basis of time or of stress in any particular case be determined; quality of electric steels.

STEEL. Modern Aircraft Engine Steels, N. L. Deuble. *Airway Age*, vol. 11, no. 2, Feb. 1930, pp. 192-196, 4 figs.

Engineer should cooperate with metallurgist to determine whether or not steel parts may be heat treated by practical methods; forging gear blanks; connecting-rod tests; narrower ranges for manufacturers; forging, heat treating and machining steel parts; design of primary importance; inspection; electric furnace steel; crankshaft steel.

AIRPLANE FUSELAGES

CORROSION PREVENTION. Fuselage Treating. *Airway Age*, vol. 11, no. 2, Feb. 1930, p. 252, 1 fig.

Description of new machine for treating fuselage structures against corrosion; time of operation reduced from 45 min. to 45 sec.; 50 per cent saving in materials; machine designed and put in operation by P. O. Gibson, of Nicholas Beazley Airplane Co., Marshall, Mo.; cylindrically shaped booth; rotary geared pump, with reversible motor, mounted on floor beneath booth to which header line is connected terminating into two tubes, which follow contour of booth and extend to slot in top.

AIRPLANE MATERIALS

SHEET STEEL. Alloy Steel Sheets for Aircraft, J. B. Johnson. *Iron Age*, vol. 125, no. 7, Feb. 13, 1930, pp. 502-505, 7 figs.

Three types of sheet steel used in aircraft described; how chrome-molybdenum thin sheets are made for heavy airplanes; physical properties and heat treatment; effects of welding; vibration failure of sheet-steel fabricated fittings due to poor

bending properties of steel; equal strength in length and breadth of sheets obtained by cross-rolling; in welding alloy sheet steel parts to be heat treated for maximum strength, one must get complete fusion of weld metal into corner of abutting sheets.

ALLOY STEEL

Modern Steels, J. H. Andrew. *Iron and Coal Trades Rev. (Lond.)*, vol. 120, no. 3232, Feb. 7, 1930, p. 243.

Iron undergoes two distinct transformations during cooling, after freezing has taken place; examination of space-lattice configuration indicates that alpha and delta iron are identical; discussion of austenitic steels; it is contended that use of alloy steels in structural work will result in diminishment of weight of metal necessary. Brief abstract of paper read before Cleveland Instn. of Engrs.

Some Lesser-Known Facts Concerning Alloy Steels, J. H. Andrew. *Mech. World (Manchester)*, vol. 7, no. 2246, Jan. 17, 1930, pp. 54-56, 3 figs.

Effect of varying amount of nickel and chromium with constant carbon content; oil hardening; problem of brittleness; example of manner in which diffusion can play important part in treatment of materials is to be found in case of high-speed cutting steel; maximum temperature from which steel is cooled. (Concluded.) Abstract of paper presented before Instn. Engrs. and Shipbuilders in Scotland.

ANTI-CORROSIVE. Recent Developments in Corrosion and Heat-Resisting Steels, R. Hadfield, T. G. Elliot and R. J. Sarjant. *Chem. and Industry (Lond.)*, vol. 49, no. 4, Jan. 24, 1930, pp. 417-517, 11 figs.

Development of non-corroding and heat-resisting steels; mechanical and physical properties of corrosion-resisting steels; photomicrographs; resistance to scaling and strength at high temperatures; industrial applications of corrosion-resisting and heat-resisting steels.

HEAT RESISTING. Alloys That Resist Heat, T. H. Nelson. *Iron Age*, vol. 125, no. 6, Feb. 6, 1930, pp. 431-434, 3 figs.

Selection of suitable material for heat resistance is not a simple problem; four classes of alloys available; corrosion and

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heat resistance are same problem; heat corrosion in domestic heaters; failure often due to chemical corrosion; special dependence on certain alloys; alloys for both corrosion and heat; special steel for valves; more nickel than chromium not essential.

STRENGTH. The Relative Safeties of Mild and High-Strength Steels under Fatigue Stresses, J. B. Kommers. *Chem. and Industry (Lond.)*, vol. 48, no. 51, Dec. 20, 1929, pp. 1223-1227, 3 figs.

Reference is made to article by B. P. Haigh in Jan. 11, 1929, issue of this journal, indexed in Engineering Index; 1929; present writer is of belief that some of conclusions drawn by Haigh are based upon insufficient experimental evidence, and that there is also considerable body of evidence which refutes some of his conclusions; he presents argument to support this belief.

ALLOY STEEL MANUFACTURE

Progress in the Manufacture of Alloy Steels, S. J. Hewitt. *Indus. Chemist (Lond.)*, vol. 6, no. 60, Jan. 1930, pp. 14-35, 1 fig.

Qualities of more important steels used in automobile manufacture; of high nickel-chromium steel, cobalt-magnet steel, and high-speed tool steel.

ALLOYS

ELECTRIC CONDUCTIVITY. Constitution of Alloys (Konstitution der Legierungen), A. Schülze. *Giesserei-Zeitung (Berlin)*, vol. 27, no. 4, Feb. 15, 1930, pp. 86-97, 21 figs.

Discussion of physical methods of analysis; electric conductivity and its bearing on constitution of alloys; heterogeneous alloys; alloys with mixed crystals; three-dimensional diagrams; use of electric conductivity for study of constitution of alloys has become important factor in metallography.

ALUMINUM

Some Applications of Aluminum, E. T. Panton. *Metal Industry (Lond.)*, vol. 36, no. 3, Jan. 17, 1930, pp. 81-84 and 103-104; 4 figs.

Progress of aluminum of recent years has been phenomenal and there is every indication that future progress of light metal of the day will be proportionately great; innumerable uses to which aluminum and its alloys are now being put are described; forms of aluminum; commercial and public vehicles; private cars; aircraft; alternatives to tin; electrical conductors; alternatives to brass and bronze; machinery construction; architectural applications; aluminum coatings; aluminum bronze.

ALUMINUM ALLOY CASTINGS

Casting of Ingots from Aluminum Alloys (Das Gießen von Walzblöcken), P. Schwerdt. *Giesserei-Zeitung, (Berlin)*, vol. 27, no. 3, Feb. 1, 1930, pp. 61-67, 3 figs.

Material employed has strength equal to that of cast or forged irons but only third of their weight; it is believed that these light alloys have all desired properties of heavier metals formerly used, with great advantage of light weight; methods of

melting and casting ingots, with special reference to duralumin, are described.

ALUMINUM ALLOYS

CORROSION. Corrosion of Aluminum Alloys (Korrosionserscheinungen an Aluminiumlegierungen), E. Maass and W. Wiederholt. *Korrosion und Metallschutz (Berlin)*, vol. 5, no. 12, Dec. 1929, pp. 265-270, 5 figs.

Results of tests to determine behavior of aluminum alloys in presence of brines, salt solutions, and under atmospheric influences.

TEMPERATURE EFFECTS. Tests on Influence of Temperature on Notch Toughness and Hardness of Aluminum Alloys (Versuche ueber den Einfluss der Temperatur auf Kerbzuehigkeit und Haerte von Aluminiumlegierungen), W. Schwinning and E. Fischer. *Zeit. fuer Metallkunde (Berlin)*, vol. 22, no. 1, Jan. 1930, pp. 1-7, 21 figs.

Notched-bar tests at temperature varying from minus 190 to plus 200 deg. cent. show basically different behavior of aluminum alloys and steel; influence of temperatures on bending strength of plates was determined also by static bending tests with unnotched specimens at temperatures between 0 and 200 deg. cent.

AUTOMOBILE GEARS

STEEL. Various Steels Are Used for Gears, N. L. Deuble. *Iron Age*, vol. 125, no. 7, Feb. 13, 1930, pp. 506-508, 1 fig.

Discussion is limited to small gears such as used in automotive industry for transmission and differentials; effect of principal alloys; oil-hardened gears are usually chromium steels; case-hardened, nickel steel; heat treatment for rapid production on machine line; typical treatment of chromium steel; question of whether transmission gears are subject to shock; advantages of carburized gears.

AUTOMOBILE MATERIALS

ALUMINUM. Light Alloys in Automobile Construction, J. B. Hoblyn. *Metallurgist (Supp. to Engineer, Lond.)*, Jan. 31, 1930, pp. 3-4.

More extended use of light alloys in automobile construction depends, author concludes, not only on their ability to withstand high duty, but on other economic conditions; he calls for further extended research and suggests number of lines for its direction. Review of paper read before Instn. Automobile Engrs. Dec. 1929 previously indexed from Metal Industry (Lond.), Dec. 13 and 20, 1929.

ALUMINUM ALLOYS. Commercial Aluminum Alloys from the Users' Point of View, J. B. Hoblyn. *Automobile Engr. (Lond.)*, vol. 20, no. 263, Jan. 1930, pp. 31-38, 21 figs.

Explanation of how certain commercial aluminum alloys in their cast and wrought conditions have behaved in reasonably stressed parts in automobiles; mechanical properties of Y alloys and duralumin in forge and heat treated states taken up; lines along which investigations might take place are indicated.

AUTOMOBILE PLANTS

HEAT TREATING FURNACES. Butane Burned in Heat Treating Furnace. C. Longenecker. *Heat Treating and Forging*, vol. 16, no. 1, Jan. 1930, pp. 100-102, 4 figs.

Description of hardening and drawing furnaces in Chrysler plant in Detroit, which are heated with butane; very satisfactory and economical operation has resulted from use of this fuel in furnaces heating axle shafts; unloading cars; storage tanks; distribution of liquid butane; advantages attending burning of butane.

AUTOMOBILE WHEELS—HUBS

ANNEALING. Equipment for Annealing Wire Wheel Hubs. W. M. Hepburn. *Machy.* (N. Y.), vol. 36, no. 6, Feb. 1930, pp. 452-453, 3 figs.

Methods employed by Wire Wheel Corporation of America, Buffalo, N. Y., in annealing redesigned wire wheel hubs; annealing installation automatically operated, even doors of furnace being opened and closed by time-clock control; press operations.

BALL BEARINGS

HEAT TREATMENT. The Heat Treatment of Ball Bearing Races. W. B. Haag and W. S. Scott. *Heat Treating and Forging*, vol. 16, no. 1, Jan. 1930, pp. 64-69, 6 figs.

Methods employed by Marlin-Rockwell Corp. in manufacture of ball bearings are discussed; electric heat applied to treatment of ball races, formerly accomplished in salt-bath furnaces fired with oil and gas, has shown decided advantages; description of rotary furnace, salt-bath furnaces, and hearth-type furnaces; saving in labor for heat treatment; decrease in labor after heat treating; increased quality and its value; better working conditions.

BARIUM-TIN ALLOYS

A Study of Barium-Tin Alloys. K. W. Ray and R. G. Thompson. *Metals and Alloys*, vol. 1, no. 7, Jan. 1930, pp. 314-316, 8 figs.

Results of investigations to prepare large number of barium-tin alloys, to study their physical properties, and to construct thermal diagram; alloys containing as high as 30 per cent barium prepared; addition of barium increased hardness and brittleness and rate of corrosion, and decreased specific gravity.

BEARING METALS

Bearing Metals. *Machy.* (Lond.), vol. 35, nos. 906, and 908, Feb. 20, 1930, p. 671, and Mar. 6, 1930, pp. 743-744.

Feb. 20: Composition and properties of yellow metal bearing alloys and copper-tin bearing alloys containing lead are given. Mar. 6: Properties and composition of tin-base alloys, lead-base alloys, zinc-base alloys, and lead-base barium alloys.

BERYLLIUM ALLOYS

Magnesium, Magnesium-Rich Alloys and Beryllium Alloys. T. H. Turner. *Metal In-*

dustry (Lond.), vol. 36, no. 3, Jan. 17, 1930, pp. 85-89, 8 figs.

Present uses of magnesium and beryllium alloys are discussed; ability to produce magnesium alloy casting at approximately same price as similar size aluminum alloy casting is surprising; machining magnesium alloy castings; magnesium sheet; resistance to corrosion; present-day applications; promising developments of beryllium has been direct production of beryllium alloys of copper and nickel to be used as temper alloys.

BOILER FIREBOXES

HEAT TREATMENT. Effect of Heat Treating Firebox Plate and Flues in the Process of Manufacture. *Boiler Maker*, vol. 30, no. 2, Feb. 1930, pp. 51-53, 7 figs.

Committee report of Master Boiler Makers' Association concerning relative merits of cold-drawn and hot-finished tubes, and conclusion is drawn that hot-finished tubes are more satisfactory product for boiler and service.

BOILER PLATES

ALLOY STEEL. Special Steels for Boiler Construction (Sonderstähle fuer den Kesselbau). M. Ulrich. *Archiv fuer Waerme-wirtschaft* (Berlin), vol. 11, no. 1, Jan. 1930, pp. 11-15, 14 figs.

Results of tests on special steels whose properties, at reasonable costs, fulfill requirements of boiler plate; aging resistance of Izett steel, was experimentally demonstrated; prolonged tests (up to 2000 hours) at 500 deg. cent. showed that molybdenum steel is greatly superior to carbon steel.

BRASS CASTINGS

The Influence of Silicon in Foundry Red Brasses. H. M. St. John, G. K. Eggleston and T. Rynalski. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 309, for mtg. Feb. 1930, 18 pp., 21 figs.

Incipient shrinkage; silicon in copper and copper alloys; factors influencing grain size; experimental procedure; experimental results; sources of silicon and its removal; discussion of results, with summary enumerating 13 conclusions drawn.

BRASS METALLOGRAPHY

The Alpha-Beta Transformation in Brass. A. J. Phillips. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 288, for mtg. Feb. 1930, 9 pp., 9 figs. See also abstract in *Fuels and Furnaces*, vol. 8, no. 3, Mar. 1930, pp. 339-340.

Experiments on 60/40 brass, on 62/38 brass and on 63/37 brass; explanation of results; conversion from beta to alpha takes place with very great rapidity if there is no change in composition.

BRITTLINESS TESTING MACHINES

New Italian Machine for Determination of Brittleness of Metals (La recente macchina italiana per la determinazione della fragilità dei metalli). E. De Latus. *Ingegneria* (Rome), vol. 3, no. 11, Nov. 1929, pp. 720-722, 4 figs.

Construction and use of machine invented by Castiello and adopted by Royal Navy of

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CADMIUM

Electrolytic Cadmium Plant of Anaconda Copper Mining Company at Great Falls, Mont. W. E. Mitchell. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 320, for mtg. Feb. 1930, 7 pp., 2 figs.

Electrolytic production of cadmium at Great Falls plant started in first part of year 1925; plant is largest producer of cadmium, not only in United States but in world; brief description of equipment and practice.

CALCIUM ALLOYS

Some New Industrial Calcium Alloys (Zur Kenntnis einiger neuer technischer Calciumlegierungen). J. Meyer and R. Goralczyk. *Zeit. fuer Angewandte Chemie (Berlin)*, vol. 43, no. 7, Feb. 15, 1930, pp. 149-154.

Report on experimental study, made at Department of Chemistry of University of Breslau, on reactive power of alloys of calcium with magnesium, aluminum, zinc and on speed of their reacting with other elements; use of calcium alloys instead of pure calcium as reducing and raising agents in making of light-weight concrete, etc.

CARS, ALUMINUM

Railroad Use of Aluminum Alloys. *Ry. Age*, vol. 88, no. 6, Feb. 8, 1930, pp. 377-380, 5 figs.

Western Railway Club discussion indicates economic advantages of this material and practicability from Shop-fabrication standpoint; performance of aluminum in Illinois Central multiple-unit cars; capital investment returned in four years; construction of aluminum cars; maintenance factors; aluminum tank cars and locomotive rods; aluminum furniture past experimental stage.

CASE HARDENING

CARBURIZING. Importance of the Binder in Carburizing Economy. H. W. McQuaid. *Black and White*, vol. 2, no. 4, Jan. 1930, pp. 9-11 and 13.

Results of several carefully conducted tests which proved that it would be economical to pay twice as much for carburizing compound made with organic binder as for one made with oil binder; percentage of energizers; losses due to shrinkage and screening; determining mixture of old and new.

CAST IRON

ELASTICITY. The Modulus of Elasticity of Cast Iron. J. E. Hurst. *Iron and Steel Industry (Lond.)*, vol. 3, no. 3, Dec. 1929, pp. 67-69, 3 figs.

Deviations in unstressed materials; determinations of stress-strain relationship; modified form of transverse loading test employed in determination of modulus of elasticity of cast iron requirements of British Engineering Standards Association specification for piston-ring materials; modulus of elasticity and constitution of cast iron.

HIGH TEST. Recent Developments in the Metallurgy of Cast Iron. R. Moldenke. *Metals and Alloys*, vol. 1, no. 7, Jan. 1930, pp. 327-328.

Outline of present-day knowledge of improving cast iron to previously not dreamed-of degree; behavior of graphite nuclei in cupola melting under increasing conditions of superheat, the higher the temperature the more complete being their solution in molten iron; microstructure of high-test cast iron predominately pearlitic.

High-Strength Cast Iron. J. S. Vanick. *Product Eng.*, vol. 1, no. 1, Jan. 1930, pp. 21-22, 2 figs.

Background of requirements and characteristics in high-test nickel irons in order to indicate their possibilities.

CAST IRON PROPERTIES

Mechanical Properties of Cast Iron (Die mechanischen Eigenschaften des Gusseisens). A. Thum and H. Ude. *F.D.I. Zeit. (Berlin)*, vol. 74, no. 9, Mar. 1, 1930, pp. 257-264, 11 figs.

General discussion of difference in mechanical properties of cast iron and steel as function of fundamental difference in their texture and structure; summary of recent determinations of tensile and compressive strength, elasticity, cohesive strength, vibration strength; impact fatigue strength of cast iron, also its behavior at notched sections; tests show that in general, cast iron behaves very much like steel at notched sections.

Gray Iron Possesses Valuable Engineering Properties. *Foundry*, vol. 58, no. 5, Mar. 1, 1930, pp. 107-110 and 142, 17 figs.

While tensile strength values of gray cast iron generally are taken from separately cast test bars, considerable work is being done to correlate this with properties that may be expected in castings; close approximation made by casting bar with twice the diameter of average or most important section of casting, and it will have approximately same cooling conditions; various properties of iron, some erroneous impressions of which are corrected.

CAST IRON TESTING

Problem of Deflection Measurement with Cast-Iron Bending Test (Kritische Betrachtungen zur Frage der Bruchdurchbiegungsmessung beim Gusseisen-Biegeversuch). A. Thum and H. Ude. *Gieserei (Duesseldorf)*, vol. 17, no. 5, Jan. 31, 1930, pp. 105-116, 17 figs.

Review of research work on measurements of bending to destruction; factors which influence determination of bending-fracture coefficients; relation of bending-fracture coefficient and bending strength to graphite content, metallic structure, and ductility of cast iron.

CASTING, CENTRIFUGAL

Centrifugal Castings and their Metallographic Analysis (Schleuderguss und seine metallkundliche Untersuchung). M. v. Schwarz and A. Vaeth. *Gieserei (Duesseldorf)*, vol. 17, nos. 8 and 9, Feb. 21, 1930, pp. 177-182, and Feb. 28, pp. 204-208, 13 figs.

Economy and advantages of centrifugal casting are set forth; main processes with horizontal axis; Bill and process with vertical axis; study of phosphorus-rich sand castings.

CASTINGS, CHILLED

HARDNESS TESTING. Hardness Testing of Hard Chill Castings (Die Pruefung der Haerte von Schalenhartguss), O. Keune, *Kruppsche Monatshefte (Essen)*, vol. 10, Dec. 1929, pp. 200-203, 2 figs.

Features of Brinell and scleroscope hardness-testing methods; it is shown, on basis of various measurements, that last-mentioned method gives widely deviating results in case of hardness testing of hard-chill castings; on other hand test results check in case of hardened steel; method for calibration of scleroscope.

CHROMIUM-NICKEL STEEL

Drawing Chrome-Nickel Alloy Utensils, *Iron Age*, vol. 125, no. 6, Feb. 6, 1930, pp. 445-446, 1 fig.

Allegheny metal used for hotel, household and hospital ware requires high heat treatment and special care in processing methods employed by Lalance and Grosjean Mfg. Co., Woodhaven, N. Y.; white pickled instead of polished sheets; heat-treated at 1900 to 1950 deg.; finished by grinding four times; welding to be used for attachments.

COPPER ALLOYS

Brass and Bronze, R. G. Johnston, *Metal Industry (Lond.)*, vol. 36, no. 3, Jan. 17, 1930, pp. 64-66, 3 figs.

Some modern uses of both bronze and brass are described; increasing attention is now given to purity of metals used in manufacture of these alloys which leads to greatly improved qualities in alloys themselves and to greater durability in service; author believes that history of metallurgy of Great Britain justifies hope that in future as in past that country will continue to lead way.

Welding Facts and Figures, D. Richardson and E. W. Birch, *Welding J.* (Lond.), vol. 26, no. 315, Dec. 1929, pp. 386-388.

Properties of copper and nickel alloys are discussed; high copper alloys have excellent welding characteristics combined with good strength; analysis of nickel alloys and methods of welding taken up.

CASTINGS. American Standards for Foundry Products (Amerikanische Normen fuer Giessereierzeugnisse), O. Schliwien-sky, *Giesserei (Duesseldorf)*, vol. 17, no. 6, Feb. 7, 1930, pp. 139-142, 4 figs.

Specifications for castings of bronze, aluminum bronze, manganese bronze, and brass, castings, issued by American Federal Specifications Board; their effectiveness in practice is subjected to constant close observation and when necessary, revised standards are issued.

HEAT CONDUCTIVITY. Thermal Conductivity of Copper Alloys, C. S. Smith, *Am. Inst. of Min. and Met. Engrs.—Tech. Pub.*, no. 291, for mtg. Feb. 1930, 23 pp., 5 figs.

Paper contains complete review of all previous work that has been done on copper alloys, and includes detailed description of apparatus and method of procedure used in present research, together with new results obtained on copper-zinc series, which is only one completed at present time; subsequent papers describing other alloys will contain experimental results and discussion only.

RECRYSTALLIZATION. Influence on Recrystallization of Copper by Addition of Second Metals Which are Absorbed in Solid Solution and Effect Partial Improvement (Ueber die Beeinflussung der Rekristallisation des Kupfers durch Zusatze zweiter Metalle, etc.), O. Dahl, *Wissenschaftliche Veroeffentlichungen aus dem Siemens-Konzern (Berlin)*, vol. 8, no. 2, July 8, 1929, pp. 157-173, 7 figs.

Addition of substances, such as zinc, tin, aluminum, phosphorus, silicon, and magnesium in various percentages, and their influence on temperature of recrystallization are investigated.

CORROSION PREVENTION

Rustless Industry, B. Jeffs, *Black and White*, vol. 2, no. 4, Jan. 1930, pp. 31 and 33-35, 3 figs.

Selection of rust preventives; inhibitive effect; tenacity of rust preventive; stability and durability; rust preventives must not stain; no one grade suitable for all conditions; economy in use.

DIE CASTING

Die Casting, A. H. Munday, *Metal Industry (Lond.)*, vol. 36, no. 2, Jan. 10, 1930, pp. 33-34.

Results of investigations of large range of alloys for die casting as well as selection of mold materials; gravity die castings preferable when mechanical properties of finished castings are chief consideration and pressure castings are to be preferred when accuracy of dimension and elimination of machining are of first importance; magnesium alloys; aluminum alloys. (Concluded.) Paper presented before Co-ordinated Soc., Birmingham.

DIES, FORGING

Construction of Drop Forging Dies, G. A. Smart, *Heat Treating and Forging*, vol. 16, no. 1, Jan. 1930, pp. 59-61 and 63, 10 figs.

Important question of proper radii and fillets for drop-forging dies is discussed and reasons for suggested practice clearly given; forging defects from improper design taken up.

ELECTRICAL FURNACES

ANNEALING. Electric Black Annealing Furnaces (Elektrische Schwarzglue-ofen), H. Langenbach, *Elektrizitaetswirtschaft (Berlin)*, vol. 29, no. 499, Jan. 1, 1930, pp. 12-13, 3 figs.

Favorable results obtained with furnace for annealing of polished wares have led to electrification of originally coal-fired furnace; performance characteristics and economics in operation of this furnace are

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ARC. Industrial Electric Heating, N. R. Stansel. *Gen. Elec. Rev.*, vol. 33, no. 2, Feb. 1930, pp. 123-129, 9 figs.

Typical three-phase installations are illustrated; general construction diagram is given; electrical features; table of energy distribution for melting period of power requirements; characteristic curves.

GERMANY. Electric Furnaces (Ueber Elektro-Ofen), V. D. I. Belani. *Montanistische Rundschau (Berlin)*, vol. 21, no. 24, Dec. 16, 1929, pp. 479-483, 4 figs.

Various types of furnaces built by Siemens and Halske A. G. are enumerated; uses to which they may be put and their special features; arc furnaces are used for production of sponge iron, of high-quality alloy steels, and of high-quality cast iron, (in conjunction with cupola), for melting scrap, and for refining (in duplex process with open-hearth furnace or bessemer converter).

HEAT TREATING. Electric Furnaces, C. L. Heisler, Jr. *Indus. Eng.*, vol. 88, no. 3, Mar. 1930, pp. 136-138, 4 figs.

Discussion of atmospheric control of electric furnaces, outstanding example of which is employed in copper-brazing process, which is used in fabrication of metallic parts; description of several types of apparatus in which atmospheric control is practiced.

Electric Furnace with Lead Bath for Tempering Steel (Hornos electricos con bano de plomo para templar acero), W. S. Stevens. *Ingenieria Internacional*, vol. 18, no. 1, Jan. 1930, pp. 38-39, 2 figs.

Use of electric furnaces does away with difficulty of temperature control; example is given of shop experience, to indicate advantage of changing from gas-fired to electric furnaces.

Electric Heat and Heat Treating Alloy Steel, T. W. Hardy. *Heat Treating and Forging*, vol. 16, no. 1, Jan. 1930, pp. 53-58, 9 figs.

Advantages gained by application of electric energy to heating more than outweigh costs; efficiency of heat transfer and improvement in quality are important; cost of annealing and heat treating including labor, maintenance, power or fuel, investment and retreatment of defective work; short- and long-cycle annealing; normalizing; heat treatment of bars; annealing of rods or wire in coils.

MELTING. Electric Cast-Iron Melting Improves Production, G. L. Simpson. *Elec. World*, vol. 95, no. 7, Feb. 15, 1930, pp. 357-358.

Tabulation of cost pertaining to melting of cast iron in Lectromelt furnace shows that electric melting saves \$2 per ton.

STEEL MAKING. Influence of Age of Furnace on Melting Time and Power Consumption of Electric Steel Furnaces (Der Einfluss des Ofenalters auf die Schmelzungsdauer und den Energieverbrauch von Elektrostahlöfen), S. Kriz and H. Kral. *Stahl und Eisen (Duesseldorf)*, vol. 50, no. 8, Feb. 20, 1930, pp. 221-222, 4 figs.

Study of melting and refining periods and power required during melting periods for

5.5-ton arc furnace in relation to age of furnace.

A Modern Electric Steel Plant (Ein neuzeitliches Elektro-Stahlwerk), K. Kerpely. *Giesserei-Zeitung (Berlin)*, vol. 27, no. 4, Feb. 15, 1930, pp. 101-102, 4 figs.

Description of new plant in Campia Turzii, Roumania, for production of iron and steel wire and wire products of all kinds; reasons are given for installing electric furnace, which is 3-phase arc type with capacity of 1 to 1.5 tons, equipped with 500-kva. 3-phase oil transformer with automatic hydraulic electrode regulation of Brown-Boveri system.

FORGING

Forging Costs by Systemization, H. R. Simonds. *Iron Trade Rev.*, vol. 86, no. 4, Jan. 23, 1930, pp. 27-30, 6 figs.

Discussion of forging methods employed by Spicer Mfg. Corp., South Plainfield, N. J., in manufacture of universal joints straight line flow of material and careful study of die design effect economies in production; lift truck handles stock; stub shaft forged without loss.

FORGING EQUIPMENT

DESIGN. Trends in the Design of Forge Equipment, M. S. Reed. *Heat Treating and Forging*, vol. 16, no. 1, Jan. 1930, pp. 51-52, 2 figs.

Year's progress in design of forging equipment is traced; standardization in design; new features on steam hammer; most of forge shops have done good volume of business during 1929.

FORGINGS

HEAT TREATMENT. Heat Treating in a Modern Forge Shop, M. J. Gorman. *Heat Treating and Forging*, vol. 16, no. 1, Jan. 1930, pp. 41-42, 3 figs.

Description of heat-treatment equipment of Moore Drop Forging Co., which consists of four continuous furnaces ranging in sizes from 13 to 21 ft. long and 6 ft. wide; handling quenching mediums; typical results of heat treatment; hardening forging and header dies.

FORGING MACHINE

Forging Machine Practice, W. S. Dewell. *Machy. (Lond.)*, vol. 35, no. 906, Feb. 20, 1930, pp. 676-677, 8 figs.

Design of forging-machine dies for making torque tube flanges is discussed; three operations are outlined.

FURNACES

ANNEALING, OIL FIRED. Oil Fired Batch Type Furnaces Used in Annealing Aluminum Sheets and Strip. *Fuels and Furnaces*, vol. 8, no. 2, Feb. 1930, pp. 261-262.

Four new batch furnaces with one double-pass firing chamber located on each side of furnace and four remodeled furnaces with carboxfrax top on firing chamber used in annealing aluminum sheets and strip.

CARBURIZING, GAS FIRED. Town Gas-Fired Carburizing Furnaces Fitted With Automatic Control, M. Van Marle. *Machy.*

(*Lond.*), vol. 35, no. 900, Jan. 9, 1930, pp. 486-489, 4 figs.

Results of tests on town gas-fired carburizing furnaces; comparison of town gas-fired and electrically heated carburizing furnaces; automatic control of gas-fired furnaces.

HEAT TREATING. Hardening and Tempering Furnaces at Ford Plant, J. B. Nealey. *Fuels and Furnaces*, vol. 8, no. 2, Feb. 1930, pp. 227-230, 2 figs.

Description of heat treating furnaces at Ford plant, including double arched and duplex conveyor types for normalizing; gas fired hardening and drawing furnaces; furnaces for hardening in cyanide and carburizing furnaces.

HEATING—REGENERATIVE. Double-Chamber Regenerative-Gas Constant-Current Furnaces (Zweikammer-Regenerativgas-Gleichstromofen), H. Fey. *Stahl und Eisen (Duesseldorf)*, vol. 50, no. 8, Feb. 20, 1930, pp. 223-229, 6 figs.

Development of ingot-heating furnaces with return flame; operation, design, and advantages of new type, patented by F. Siemens Corp., Berlin; it can be heated with blast-furnace gas without preheating in chambers; elimination of gas chamber makes these furnaces more explosion-proof; this furnace, heated with uniform flame, produces over whole length uniformly heated ingots.

GALVANIZED IRON

WELDING. How to Weld Galvanized Iron, A. G. Wikoff. *Am. Welding Soc. J.*, vol. 9, no. 1, Jan. 1930, pp. 23-27 and (discussion) 34-35, 8 figs.

Welding of galvanized material results in loss of certain amount of zinc coating from surface immediately adjacent to welds; welding galvanized iron with steel welding rods; experience seems to indicate that welded joint in galvanized pipe is as good as screw-coupled joint so far as internal corrosion is concerned; bronze-welded galvanized iron pipe; bronze welding galvanized sheet.

GAS ANALYSIS APPARATUS

A Simple Control Stopcock for Gas Analysis Apparatus, M. Shepherd. *U. S. Bur. Standards—Jl. of Research*, vol. 4, no. 1, Jan. 1930, pp. 23-26, 2 figs.

Note describes simple control stopcock for gas-analysis apparatus; control permits pressure balance to be obtained easily, quickly and with high accuracy; diffusion errors are eliminated without danger of emptying manometer; accidental surge of pipette reagents into train is prevented; difficult combustions of heavy hydrocarbons may be made without deposition of carbon; technique of operation and actual means of construction of stopcock are described.

GEARS AND GEARING

NITRIDATION. Nitralloy and the Nitrogen Hardening Process, F. W. Rowe. *Machy. (Lond.)*, vol. 35, no. 904, Feb. 6, 1930, pp. 601-602.

Description of methods employed by David Brown and Sons, Huddersfield, in manufacturing gears; maximum tensile strength of

nitralloy steels for gears; temperature for nitriding; disadvantage of high-temperature nitriding; limitations due to shallow case and to brittleness; resistance to abrasive wear; essential qualities of metal employed for valve disks and seats for superheated steam.

HARDNESS TESTING INSTRUMENTS

The Monotron Hardness Indicator, *Engineering (Lond.)*, vol. 129, no. 3345, Feb. 21, 1930, p. 252, 1 fig.

Instrument made by Shore Instrument and Manufacturing Co., of New York, can be used for determining hardness of all metals, from superhardened steel to lead, as well as of organic substances such as rubber and wood; diamond used is 0.75 mm. in diam. and depth of standard impression is 0.0018 in.

HARDNESS TESTING MACHINES

Entire Surfaces Tested for Hardness by Cloudburst Instruments. *Automotive Industries*, vol. 62, no. 11, Mar. 15, 1930, pp. 445-446, 4 figs.

Description of Herbert Cloudburst machine for testing hardness of metals; measuring device shows location of soft spots by means of curtain of steel balls dropped on material under inspection; height of fall is so chosen that if article under test is of proper hardness balls do not produce any marks on it; in motor driven machines 250,000 steel balls of $\frac{1}{8}$ in. diam. are used and are raised by means of chain elevator to height of 4 m.; use of machine for surface hardening parts.

New Hardness Testers (Neuere Haertepruefer), Roemmelt. *V.D.I. Zeit. (Berlin)*, vol. 74, no. 9, Mar. 1, 1930, p. 272, 3 figs.

Descriptive notes on pedestal type of testing machine for determination of Brinell hardness of flat and cylindrical surfaces; machine is manufactured by Mohr and Federhaff of Mannheim, Germany.

HEAT TREATMENT

Economics and Economics of Heat-Treating, R. M. Keeney. *Am. Mach.*, vol. 72, no. 5, Jan. 30, 1930, pp. 225-227, 3 figs.

Selection of source of heat for industrial heat-treatment of metals discussed; items influencing overall cost; various applications of annealing furnaces in Connecticut; fuels for annealing brass; measurable progress has been made in atmospheric control of electric furnaces for bright-annealing copper; for annealing nickel-silver stampings, electric furnaces increasingly used. Abstract of paper read before Am. Soc. Steel Treating.

PHYSICAL CHEMISTRY. What a Heat Treater Should Know About Physical Chemistry, G. M. Enos. *Fuels and Furnaces*, vol. 8, no. 3, Mar. 1930, pp. 321-326, 5 figs.

Discussion of changes which can be brought about in solid metals and alloys by application of heat; flow of heat and flow of gases; phase changes; equilibrium grams.

IMPACT TESTING

NOTCHED BAR. Stresses in Fatigue Impact Testing (Zur Frage der Beanspruch-

ung beim Dauerschlagversuch), A. Thum and S. Berg. *V. D. I. Zeit. (Berlin)*, vol. 74, no. 7, Feb. 15, 1930, pp. 200-204, 12 figs.

Condensed report on experimental study made at Darmstadt Institute of Technology; effect of elastic hysteresis and notching on magnitude of stresses caused by impact, with special reference to maximum stresses; lines of force at abrupt changes in cross-sections of specimens; diagram of distribution of stress intensities at notches; photographs of fractures. Full report published in Bul. No. 331, Forschungsarbeiten auf dem Gebiete des Ingenieurwesens.

IRON

ELECTROLYTIC. Electrolytic Iron from Sulfide Ores. R. D. Pike, G. H. West, L. V. Steck, R. Cummings and B. P. Little. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 268, Feb. 1930, 35 pp., 18 figs.

Description in detail of pilot-plant operation for producing iron of almost complete chemical purity and in dense homogeneous form from sulphide ores or materials containing metallic iron; process requires use of cell with diaphragm and hot electrolyte; outline of process for producing pure electrolytic iron as porous cathodes from scrap, employing simple non-diaphragm cell and cold electrolyte.

X-RAY ANALYSIS. X-ray Notes on the Iron-Molybdenum and Iron-Tungsten Systems. E. P. Chartkoff, and W. P. Sykes. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 307, for mtg. Feb. 1930, 10 pp., 6 figs.

Notes on work supplementing that described by Sykes in paper indexed in Engineering Index, 1926, p. 433; measurements were made of changes in lattice parameters in solid solutions; precipitation from solid solution and accompanying changes in hardness were studied as well as formation of intermetallic compound phases upon sintering mixture of metal powders. Bibliography.

IRON CRYSTALS

Production and Some Properties of Large Iron Crystals. N. A. Ziegler. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 273, for mtg. Feb. 1930, 18 pp., 22 figs.

Report on investigation that is part of magnetic research work on iron and iron alloys, undertaken to obtain, if possible, magnetic research work on iron and iron deals primarily with preparation of single crystals of iron and their mechanical properties. Bibliography.

IRON METALLOGRAPHY

ALPHA VEINING. The Relation between Alpha-Veining and the A-3 Change in Iron. E. Ammermann and H. Kornfeld. *Metals and Alloys*, vol. 1, No. 7, Jan. 1930, pp. 334-335, 1 fig.

Ferrite free from alpha-veining can be obtained by recrystallization, below A-3, of previously cold-worked material; veining occurs only when iron (ferrite) is transformed into gamma condition; deformation below A-3 does not cause veining, although it

does promote its formation if some veining already exists, as result of other factors (as low-carbon steel). Translated from Archiv fuer Eisenhuettenwesen, Oct. 1929.

IRON-NICKEL ALLOYS

COBALT ADDITIONS. Expansion Properties of Low-Expansion Fe-Ni-Co Alloys. H. Scott. *Am. Inst. of Min. and Met. Engrs.—Tech. Pub.*, no. 318, for mtg. Feb. 1930, 34 pp., 20 figs.

Discovery of Brace (U. S. Patent 1,689,814) that addition of cobalt lowers expansivity of low-expansion nickel-iron alloys, suggested detailed investigation of iron-nickel-cobalt system, with object of determining optimum compositions and their associated expansion properties; results of such an investigation are described.

IRON-NITROGEN ALLOYS

Changes in Properties of Iron-Nitrogen Alloys Due to Quenching and Annealing below A-1 (Ueber die Eigenschaftsänderungen der Eisen-Stickstoff-Legierungen durch Abschrecken und Anlassen unterhalb A-1), W. Koester. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 8, Feb. 30, 1930, pp. 553-558, 12 figs.

Influence of nitrogen diagram of state on properties of iron-nitrogen alloys; brittleness of solid solution of iron-nitrogen conditions for dissolution and separation of nitrogen; influence of heat treatment on structure and strength; and on magnetic properties; effect of etching on iron containing nitrogen.

IRON-PHOSPHORUS ALLOYS

Iron-Phosphorus-Carbon System (Ueber das System Eisen-Phosphor-Kohlenstoff), R. Vogel. *Stahl und Eisen (Duesseldorf)*, vol. 50, no. 1, Jan. 2, 1930, pp. 14-15, 1 fig.

Results of investigation; crystallization of alloys with 10 to 21 per cent phosphorus; saturation limit of iron-phosphorus mixed crystals; diagrams of state of iron-phosphorus and iron-phosphorus-carbon systems; transformation of mixed crystals in solid state. Abstract of article indexed in Engineering Index 1929.

IRON-SILICON ALLOYS

Progress Notes on the Iron-Silicon Equilibrium Diagram. B. Stoughton and E. S. Greiner. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 309, for mtg. Feb. 1930, 33 pp., 27 figs.

Existing data on constitution of iron-silicon alloys were compiled and correlated, and an investigation was carried out on iron-silicon alloys containing less than 10 per cent silicon; micrographic and hardness tests were made; tentative equilibrium diagram of iron-silicon system was proposed.

IRON AND STEEL

PROTECTIVE COATINGS. Protective Coatings for Iron and Steel. E. O. Jones. *Chem. Age (Lond.)*, vol. 22, no. 553, Feb. 1, 1930, pp. 8-9.

Discussion of various types of protective coatings which are: another more resistant metal; paint, lacquer or varnish; tarry or bituminous paint; cement or concrete; glassy enamels; oxide or phosphate films; or films of grease or oil; discussion of ap-

plication of metallic coatings; dipping, electrodeposition, sherardizing, calorizing, chromizing, and metal-spraying processes.

IRON AND STEEL TESTING

Iron and Steel Products Tested To Insure Safety in Construction, H. L. Whittemore, *Commercial Standards Monthly*, vol. 6, no. 7, Jan. 1930, pp. 189-190, 2 figs.

Brief description of research conducted by Bureau of Standards on improvements and economies in structural materials; test of materials; test of materials for Hudson River bridge; strength of pad eyes for submarines; locking screw threads; welded steel tubing; welded joints for aircraft.

LEAD ALLOYS

ANALYSIS. Rapid Volumetric Method for the Determination of Lead, R. C. Wiley, *Indus. and Eng. Chem.—Analytical Edition*, vol. 2, no. 1, Jan. 15, 1930, pp. 124-126.

Accurate and rapid method has been described for determination of lead in alloys which contain, in addition, antimony and tin; indicator is extremely sensitive to small quantities of molybdenum; with care in manipulation; it is believed that this method is capable of extreme accuracy; method should prove useful for determination of lead in ores.

LOCOMOTIVE MANUFACTURE

ALLOY STEEL. Alloy Steels in Locomotive Construction, W. M. Barr, *Western Ry. Club—Proc.*, vol. 42, no. 3, Nov. 1929, pp. 10-27.

Discussion of conditions which have caused designers to turn to alloy steels; use of chromium, vanadium in locomotive forgings; metallographic results of several test pieces.

LOCOMOTIVES

FORGINGS. Higher Quality Locomotive Forgings, W. J. Knight, *Railroad Herald*, vol. 34, no. 3, Feb. 1930, pp. 27-29.

Discussion of factors affecting construction of high-quality locomotive forgings; steel composition; consideration of method of heat-treating all steels after they have been shaped by forging.

MANGANESE STEEL

Manganese in Simple Steels, H. S. Hibbard, *Fuels and Furnaces*, vol. 8, no. 3, Mar. 1930, pp. 391-393.

Discussion covering function of manganese in clearing metal of oxides and tendency of manganese to regulate boil of bath. (To be continued.)

Manganese Hard Steel (Mangan-Hartstahl), K. H. von Scheele, *Glaser-Zeitung (Berlin)*, vol. 27, no. 4, Feb. 15, 1930, pp. 98-100, 3 figs.

Notes on present status of manufacture; it is shown that knowledge of high-per cent manganese steel, in spite of developments in recent years, is not yet complete; practical scientific tests are necessary to determine durability of manganese hard steels of different compositions.

MAGNESIUM ALLOYS

Magnesium, Magnesium-Rich Alloys and

Beryllium Alloys, T. H. Turner, *Metal Industry (Lond.)*, vol. 36, no. 3, Jan. 17, 1930, pp. 85-89, 8 figs.

Present uses of magnesium and beryllium alloys are discussed; ability to produce magnesium alloy casting at approximately same price as similar size aluminum alloy casting is surprising; machining magnesium alloy castings; magnesium sheet; resistance to corrosion; present-day applications; promising developments of beryllium has been direct production of beryllium alloys of copper and nickel to be used as temper alloys.

MALLEABLE CAST IRON MOLDS

Cupola Malleable Is Cast in Permanent Molds, H. W. Hyde, *Foundry*, vol. 58, no. 5, Mar. 1, 1930, pp. 104-106, 1 fig.

Development and application of iron molds for cupola malleable practice are discussed; advantages of chill molds; graphite causes cracks; machine used for operation of molds described. (To be continued.)

MANGANESE STEEL

DRILLING. Drilling Manganese Steel with Slag Major Special Type Twist Drills, Machy, (Lond.), vol. 35, no. 903, Jan. 30, 1930, pp. 581-582.

Results of experiments undertaken in drilling manganese steel with special design twist drills of Slag Major high speed steel; cutting special speed range; re-starting in partially drilled hole; relation between depths and diameter; explanation of difficulty in machining manganese steel; rate of speed per revolution; number of holes per grind on production drilling.

MATERIALS TESTING

Endurance of Fatigue Testing of Materials, Machy, (Lond.), vol. 35, no. 900, Jan. 9, 1930, pp. 473-478, 7 figs.

Description of various materials-testing systems which are based on fact that in neighborhood of endurance strength limit test piece will be weakened in its inner structure; Schenck endurance testing machine; fatigue testing by torsional oscillation; effect of surface conditions on fatigue strength; effect of static preliminary loads; new Losenhausenwerk fatigue-testing machine; method of plotting static and dynamic curves; tests with cooled specimens.

Testing Methods and Apparatus, E. A. Alcott, *Can. Machy. (Toronto)*, vol. 41, no. 1, Jan. 9, 1930, p. 42.

Details of hydraulic machines used in testing, accuracy of which depends upon knife-edges. (Concluded.)

METALLURGY

Fifty Years of Physical Metallurgy, H. M. Boylston, *Metals and Alloys*, vol. 1, no. 7, Jan. 1930, pp. 329-331.

Early history of physical metallurgy is outlined; definition of physical metallurgy and difference between this and metallography; early developments of metallographic equipment; steel-hardening theories; crystalline growth in metals; Neumann bands; iron-carbon diagrams. Abstract of paper presented before World Eng. Congress, Tokyo.

1930

METALS

ELECTRIC CONDUCTIVITY. Superconductivity of Metals and Alloys (Ueber die Supraleitfähigkeit der Metalle und Legierungen), A. Schulze. *V. D. I. Zeit. (Berlin)*, vol. 74, no. 5, Feb. 1, 1930, pp. 149-152, 5 figs.

Review of works which discuss electric superconductivity of metals and alloys and which, through their relation to other properties, form contribution to knowledge of phenomenon.

GROWTH. Unusual Crystal Growth of Iron and Copper and its Causes (Ausergewöhnliches Kristallwachstum an Eisen und Kupfer und seine Ursachen), R. Kuehnel. *Zeit. fuer Metallkunde (Berlin)*, vol. 22, no. 2, Feb. 1930, pp. 53-54 and (discussion), p. 55, 11 figs.

Cases of failures in metals have occurred, due to faulty treatment, in which changes in structure were noted which it was almost impossible to intentionally reproduce; three cases described refer to a case-hardened steel, a firebox copper, and a forged steel.

PASSIVITY. A Further Survey of W. J. Mueller's recent Work on Passivity, W. J. Mueller and U. R. Evans. *Chem. and Industry (Lond.)*, vol. 49, no. 5, Jan. 31, 1930, pp. 66T-69T.

Brief note on nomenclature of anodic passivity; decay of current with time during production of passivity; time needed to produce passivity; oxide films and passivity. Translated review of address delivered in 1928 before Ausschuss fuer Metallschutz.

A Further Survey of W. J. Mueller's Recent Work on Passivity, U. R. Evans. *Chem. and Industry (Lond.)*, vol. 49, no. 7, Feb. 14, 1930, pp. 92T-93T.

Continuation of Mueller's address to Bunsengesellschaft; time of passivation is tabulated for iron anode treated with unit current density in sulphuric acid of various concentrations; study of lead and aluminum anodes.

TEMPERATURE EFFECT. Qualities of Construction Materials at High Temperature (Werkstoffeigenschaften bei hoherer Temperatur), M. Ulrich. *Maschinenbau (Berlin)*, vol. 9, no. 2, Jan. 16, 1930, pp. 59-60, 1 fig.

Creep-limiting values are discussed; tabulation and curves of creep-tension tests are given.

Effect of Small Changes in Temperature on the Properties of Bodies, M. D. Hersey. *U. S. Bur. of Standards—Jl. of Research*, vol. 4, no. 1, Jan. 1930, pp. 137-156.

After reviewing usual methods of solution, general mathematical treatment of problem is given, from which two additional methods are derived that can sometimes be usefully applied: (1) simple calculation, made possible by theory of dimensions, which does not require detailed formula for property in question; and (2) combined theoretical and experimental solution, in which experimental factors have been reduced to minimum; stiffness of steel spring is taken as example.

METALS CORROSION

Corrosion of Alloys Subjected to the Ac-

tion of Locomotive Smoke, F. L. Wolf. *Am. Inst. Min. and Met. Engr.—Tech. Pub.*, no. 293, for mtg. Feb. 1930, 16 pp., 6 figs.

Results of service test and accelerated test on several commercial metals and alloys are not entirely conclusive, but give indication of relative value of various types of alloys commercially available for overhead construction work for steam railroad electrification purposes; alloys which stand up well under various other forms of corrosion have failed when subjected to locomotive smoke.

METALS FATIGUE

The Failure of Steel Castings and Forgings Through Fatigue. *North-East Coast Inst. of Engr. and Shipbldrs.—Advance Paper (Newcastle-Upon-Tyne)*, for mtg. Jan. 24, 1930, 14 pp., 4 figs. on supp. plates.

Rather loose application of term fatigue is discussed; one type of fracture only is classed as fatigue fracture, others described being barred; erroneous conceptions of fatigue are discussed and its mechanism is described; metallurgical and mechanical aspects are dealt with, and ways of avoiding fatigue are suggested; number of examples of fatigue failures are briefly described.

More on Fatigue and High Frequency Fatigue Testing. *Metals and Alloys*, vol. 1, no. 7, Jan. 1930, pp. 332-333.

Review of two papers, namely, High Frequency Fatigue, C. F. Jenkin and G. D. Lehmann, and Fatigue of Metals, review of progress from 1920 to 1929, H. F. Moore; it is not clear just how sure one may be that stresses calculated for narrow specimen are true; were it not that unpublished work at Bureau of Standards shows exactly opposite condition, work of Jenkin and Lehmann would appear to be quite conclusive.

METALS TESTING

The Relation Between the Tensile Strength and the Hardness of Metals, O. Schwartz. *Nat. Advisory Committee for Aeronautics—Tech. Memo.*, no. 552, Feb. 1930, 15 pp., 16 figs. on supp. plates.

In case of non-ferrous metals there exists, even for metals of same group, aluminum and its alloys excepted; no linear relation between Brinell hardness and tensile strength; conversion factors depend on degree of cold working and may vary between 0.3 and 0.6; effect and dependence of hardness numbers on strain-hardening; procedure for finding Brinell strength; conditions at higher temperatures and for cast metals. From *V. D. I. Zeit.*, June 8, 1929.

TENSILE. Deformation Phenomenon in Tensile Bars (Beitraege zum Verformungsvorgang in Zerreisstaeben), W. Tafel and H. Scholz. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 8, Feb. 1930, pp. 545-552, 16 figs.

Study of deformation of crystalline bodies; deformation of fixed ends of tensile bars and influence of height of end on location of fracture; new method of measuring grain size for determination of deformation of crystals; results of grain-measurement.

NICKEL ALLOYS

Welding Facts and Figures, D. Richard.

son and E. W. Birch. *Welding J. (Lond.)*, vol. 26, no. 315, Dec. 1929, pp. 386-388.

Properties of copper and nickel alloys are discussed; high copper alloys have excellent welding characteristics combined with good strength; analysis of nickel alloys and methods of welding taken up.

NICKEL FOUNDRY PRACTICE

Monel Metal and Nickel Foundry Practice, E. S. Wheeler. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 298, for mtg. Feb. 1930, 9 pp., 4 figs.; see also abstract in *Fuels and Furnaces*, vol. 8, no. 3, Mar. 1930, pp. 339-340.

Monel metal and nickel are both harmfully susceptible to action of gases; manganese causes heavy shrink; sulphur in excess of 0.03 per cent makes metal hot, short and brittle; use of scrap is frequently responsible for heavy pulls and sometimes causes porosity; without proper furnaces, good molding or good foundry practice cannot produce satisfactory castings.

NITRIDATION

Nitriding of Steel in European Practice, J. W. Urquhart. *Heat Treating and Forging*, vol. 16, no. 1, Jan. 1930, pp. 48-50 and 52.

Ammonia-heat method of producing intense local hardness is reviewed; aluminum content is indispensable; hardness of case is comparable to bort; properties of nitrided steel surface; low temperature advantages of nitriding; depth of nitrided zone; preparation of nitralloy steels; steels suggested for nitriding; firing boxes for nitriding; electric resistor furnace used in Europe for nitriding.

NITRIDED STEEL

CORROSION. Corrosion of Cemented or Nitrided Steels (La corrosion des aciers cémentés ou nitrés), L. Guillet and M. Ballay. *Académie des Sciences—Comptes Rendus (Paris)*, vol. 189, no. 23, Dec. 2, 1929, pp. 961-963.

Nitridation increased corrodibility of steels by 5 per cent sulphuric or hydrochloric acid with exception of steel containing 4.08 per cent nitrogen, 0.91 per cent chromium, resistance of which towards former acid was increased; for chromium-aluminum steels cementation had same effect; cementation slightly increased resistance towards 10 per cent copper-sulphate solution, but nitrided steels were hardly attacked.

PIG IRON MANUFACTURE

ELECTRIC PROCESS. Production of Gray Iron from Steel Scrap in the Electric Furnace, T. F. Bailey. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 296, for mtg. Feb. 1930, 17 pp., 15 figs.

Description of experimental work at plant of Bailey Furnace Co., Canton, Ohio; illustrations of furnace, tabular analyses, results of transverse and deflection tests, and photomicrographs are given.

RAILROAD ROLLING STOCK MATERIALS

FATIGUE TESTING. Fatigue Failure and Fatigue Resistance (Dauerbruch und

Dauerfestigkeit), R. Kuehnelt. *V. D. I. Zeit. (Berlin)*, vol. 74, no. 6, Feb. 8, 1930, pp. 181-184, 16 figs.

Special test data and results of operating experience of railroad administration of Germany; studies of fatigue fractures observed in crossheads, wheel flanges, axles, springs and other elements of locomotives and cars; impact fatigue tests of various special steels and cast iron. Paper read before German and Austrian Soc. for Testing of Eng. Materials.

RAILS

SEGREGATION. Inverse Segregations As Cause of Rail Fractures (Segregações negativas como causa de fracturas de trilhos), V. B. Da Costa Pinto. *Boletim do Instituto de Engenharia (Sao Paulo)*, vol. 11, no. 55, Dec. 1929, pp. 438-440, 7 figs.

Discussion of origin of segregation of included impurities in rolled blooms; methods of testing rails for defects are suggested; examples of chemical analyses are given.

REFRACTORY MATERIALS

HEAT CONDUCTIVITY. Measuring Thermal Conductivity of Refractory Materials at High Temperatures (Waermeleitfähigkeitsmessungen und Feuerfesten Materialien bei Hohen Temperaturen), A. Eucken and H. Laube. *Technische Zeitschrift (Berlin)*, vol. 53, no. 91, Nov. 14, 1929, pp. 1599-1602, 4 figs.

Spherical heating element wound with platinum wire is used; material to be tested is made into two hemispheres surrounding heating elements; thermocouples are embedded in concentric grooves and lead wires are brought to surface at considerable distance from junctions.

SHEET METAL TESTING

The Practical Testing of Sheet and Strip for Drawing Operations, L. N. Brown. *Metal Stampings*, vol. 3, no. 3, Mar. 1930, pp. 239-242 and 270, 4 figs.

Discussion of scientific methods for specification of drawing qualities and thickness of strip and sheet; types of testing machines and testing methods; use of load and cup depth to indicate comparable drawing qualities.

STAINLESS STEEL

Corrosion-Resisting Steels and Their Applications, J. H. G. Monypenny. *Iron and Steel Industry (Lond.)*, vol. 3, no. 4, Jan. 1930, pp. 111-115, 4 figs.

General characteristics and mechanical properties of corrosion-resisting steels; difficulties in manufacture of stainless steel of very low carbon content; improvement effected by increasing chromium; if nickel content of austenitic steels be considerably increased their usefulness is extended in certain directions mainly with regard to meeting corrosive attack of certain type at high temperature. (To be continued.)

STEEL

STRAIN HARDENING. Overload Capacity and Dynamic Strain Hardening of Steels (Ueber dynamische Verfestigung und Ueberlastungsfähigkeit von Stählen), A.

Thum. *V. D. I. Zeit. (Berlin)*, vol. 73, no. 50; Dec. 14, 1929, pp. 1787-1788, 5 figs.

Excerpts from thesis presented to Darmstadt Institute of Technology; report on experimental studies of so-called strain hardening of steel to withstand higher repeated stresses; experiments with pre-stressed materials; temperature regime for various fatigue-testing procedures.

SURFACE HARDENING. The Surface Hardening of Steel, F. W. Rowe. *Iron and Steel Industry (Lond.)*, vol. 3, no. 3, Dec. 1929, pp. 77-80, 9 figs., vol. 3, no. 4, Jan. 1930, pp. 116-119, 7 figs.

Dec.: Cementation with solid compounds; properties desired in carburizing compounds; disguising of over-carburization; mechanism of carburizing; design of furnaces and boxes; electric furnaces; working costs; steels for case hardening. Jan.: Cementation with gases; cyanide hardening; nitralloy steel and nitrogen hardening; Shorter process of surface hardening. Paper presented before Manchester Met. Soc. (Concluded.)

STEEL ANALYSIS

CARBON DETERMINATION. Determination of Carbon in High Melting Alloys Using High Frequency Induction Furnace, G. F. Smith and G. L. Hockenyoos. *Indus. and Eng. Chem.—Analytical Edition*, vol. 2, no. 1, Jan. 15, 1930, pp. 36-38, 5 figs.

Determination of carbon in steel by direct combustion in oxygen at 900 to 1100 deg. cent. gives satisfactory results only if sample completely fuses during oxidation; combustion train, materials and operation; experimental results.

STEEL FATIGUE

The Failure of Steel Castings and Forgings Through "Fatigue", R. A. MacGregor. *North-East Coast Instn. of Engrs. and Shipbuilders—Advance Paper (Newcastle-upon-Tyne)*, Jan. 24, 1930, 14 pp., 4 figs.

Rather loose application of term fatigue is discussed; metals neither become tired nor recrystallized in service, but owing to over-stressing actual partition takes place and fatigue is then imminent; erroneous conceptions of fatigue; characteristics common to all fatigue fractures; list of initiating conditions leading to fatigue cracking; metallurgical and mechanical aspects.

Failure of Steel Castings and Forgings, R. A. MacGregor. *Iron and Coal Trades Rev. (Lond.)*, vol. 120, no. 3232, Feb. 7, 1930, p. 249.

Higher stresses are now common in modern construction; conditions predisposing to failure by fatigue are initiated by breaking of first crystal; author described appearance of fatigue fracture, and outlined conditions likely to induce fatigue; elastic-limit function; mechanical aspects of fatigue failures; specific instances of fatigue failures arising from various causes are given in original paper. Brief abstracts of paper read before North-East Coast Instn. Engrs. and Shipbuilders.

STEEL FORGING

The Manufacture of Large Steel Forgings, A. O. Schaefer. *Heat Treating and Forging*, vol. 16, no. 1, Jan. 1930, pp. 43-47, 9 figs.

Special precautions to be taken in manufacture of very large steel forgings are outlined with steel makers' attitude with regard to this particular product; history of ingot for very large forgings; heat treatment; inspection and testing; inspection of central portion.

STEEL GALVANIZING

Hot Galvanizing As It Affects Mild Steel, J. C. Allan and R. L. Geruso. *Heat Treating and Forging*, vol. 16, no. 1, Jan. 1930, pp. 70-75, 19 figs.

Discussion of effect of hot galvanizing on physical properties of cold-worked steel, which has been studied with particular reference to bolt-steel grades; galvanizing affects deleteriously physical properties of cold-worked steel to even greater extent than if steel is merely annealed at 440 deg. cent. after overstrain; common failures of galvanized bolts are analyzed; cold-worked steel should be thoroughly annealed before galvanizing.

STEEL INGOTS

CASTING MACHINES. Steel Billets Are Cast Centrifugally, J. D. Knox. *Iron Trade Rev.*, vol. 86, no. 5, Jan. 30, 1930, pp. 58-60, 4 figs.

Description of machine which, by centrifugal means, casts eight bars 78 in. long, 18 in. wide, and from ½ to 4 in. thick at one time; machine was designed by L. Cammen; unit includes driving medium, pouring trough and cylindrical mold partially fluted on interior; use of casting machine makes soaking pits unnecessary; continuous furnace with racks for storing bars required.

STEEL MANUFACTURE

CHEMICAL REACTIONS. Studies of Manganese and Phosphorus Reactions in the Basic Steel Manufacturing Process (Untersuchungen ueber den Verlauf der Mangan- und Phosphorreaktionen bei den basischen Stahlerzeugungsverfahren), H. Schenck. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 8, Feb. 1930, pp. 505-530, 12 figs.

Importance of state of equilibrium is pointed out; utilization values of reactions; binding of phosphoric acid in slag; silicate compounds in slags; free ferrous oxide and lime in slag; equilibrium conditions for reactions of manganese and phosphorus; examination of Herty's Laws of manganese reactions.

RESEARCH. A New Method for Determining Iron Oxide in Liquid Steel, C. H. Herty, J. M. Gaines, Jr., H. Freeman and M. W. Lightner. *Am. Instn. Min. and Met. Engrs.—Tech. Pub.*, no. 311, for mtg. Feb. 1930, 13 pp., 3 figs.

Notes on investigation to obtain true value of oxygen content of liquid steel; description of method by deoxidation of liquid steel with aluminum; effect of excess aluminum added; effect of aluminum on oxides other than FeO; analytical method for determination of alumina; open-hearth tests; preliminary studies of basic open-hearth heat, and of acid open-hearth heat. Bibliography.

STEEL METALLOGRAPHY

Influence of Rate of Cooling on Dendritic Structure and Microstructure of Some Hypoeutectoid Steel, A. Sauveur, and C. H. Chou. *Am. Inst. of Min. and Met. Engrs.—Tech. Pub.*, no. 299, for mtg. Feb. 1930, 16 pp., 32 figs.

Steel selected was of commercial grade; after melting in vacuum in an Arsem furnace, various samples were allowed to solidify and to cool to room temperatures indicated; results of experiments are described chiefly by illustrations.

CRYSTALLIZATION. Steel Crystals, J. S. Glen Primrose. *West of Scotland Iron and Steel Inst.—Jl. (Glasgow)*, vol. 37, Oct. 1929, p. 13, 4 figs.

Discussion of steel crystals is given with illustrations showing among other things stages in crystal growth.

STEEL HEAT TREATMENT

QUENCHING. Modern Quenching, E. H. MacInnis. *Black and White*, vol. 2, no. 4, Jan. 1930, pp. 14-16.

Water quenching versus oil quenching is discussed with its effects of machinability; water quenching does not produce uniform hardness; cooling speed of water varies; water quenching often costly.

STEEL RESEARCH

Steel Research, J. H. Andrew. *West of Scotland Iron and Steel Inst.—Jl. (Glasgow)*, vol. 37, Nov. 1929, pp. 17-21 and (discussion) 21-23.

Relation between science and practice in steel research is discussed with present day attitude of industrialists towards scientific work; problems of production of sound ingots; possible methods of improving existing attitudes and conditions towards science.

STEEL TESTING

Endurance Properties of Steel in Steam, T. A. Fuller. *Am. Inst. of Min. and Met. Engrs.—Tech. Pub.*, no. 294, for mtg. Feb. 1930, 13 pp., 15 figs.

Description of preliminary experiments; investigation outlined to determine combined effects of steam and temperature; work reported deals chiefly with nickel steel, with one series of tests including nitrided steel; endurance limit of nickel steel is lower in steam than in air at room temperature; endurance limit of 65,000 lb. per sq. in. was obtained with specimens of nitrided steel.

TENSILE. Tensile Properties of Rail and Other Steels at Elevated Temperatures, J. R. Freeman, Jr., and G. W. Quick. *Am. Inst. of Min. and Met. Engrs.—Tech. Pub.*, no. 269, for mtg. Feb. 1930, 48 pp., 38 figs.

Notes on special study of tensile properties, in approximate temperature range of 400 to 700 deg. cent.; ductility decreases with temperature increase, over portion of range; elongation and reduction of area decrease at 500 to 650 deg.; data on rate of cooling and temperature distribution are also given. Bibliography.

TIN ALLOYS

Tin, and the Alloys of Tin, Lead and Antimony, G. N. Nicklin. *Metal Indus-*

try (Lond.), vol. 36, no. 3, Jan. 17, 1930, pp. 67-79 and 90, 15 figs.

Present situation of tin industry is discussed; metallurgy and physical characteristics of tin alloys; important industrial application of tin-lead-antimony alloys is found in their use as type metals; working temperatures of printing alloys.

TOOL STEEL

HEAT TREATMENT. Procedure in Hardening of Steel Tools, A. H. Hert. *Can. Machy. (Toronto)*, vol. 40, no. 26, Dec. 26, 1929, pp. 295-296.

Precautions to be observed in heat treating steel tools are described; plugging holes in steel advisable; rolling the pieces; critical point; warping in bath; system can be worked out by aid of stereoscope that would overcome nearly all troubles in tempering carbon steel.

Heat Treatment of Carbon Tool Steel, H. M. Boylston. *Black and White*, vol. 2, no. 4, Jan. 1930, pp. 3-8, 8 figs.

Troubles encountered in heat treatment of carbon tool steel outlined; grades of tool steels; mechanical working annealing; avoiding decarburization; normalizing; avoiding overheating; burning temperatures.

TORSION TESTING MACHINES

Machines for Determining Torsional Fatigue Developed in Germany. *Automotive Industries*, vol. 62, no. 6, Feb. 8, 1930, pp. 193-194, 2 figs.

Description of two machines for testing specimens for endurance under alternating torsional loads; one, manufactured by Losenhausenwerk of Duesseldorf Machine Works, subjects specimen to fixed preliminary torsional load superimposed upon which is rapidly alternating torsional load; other, manufactured by Carl Schenk Foundry and Machine Works, Darmstadt, test specimen is coupled to measuring spring bar and forms extension of it.

TUBES, BRASS

Internal Stress and Season Cracking in Brass Tubes, D. K. Crampton. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 297, for mtg. Feb. 1930, 18 pp., 11 figs.

Résumé of literature; description of investigations; correlation between mercurous nitrate tests and actual season cracking on long-time atmospheric exposure; quantitative effect of type and degree of drawing operations on intensity of internal stress and on tendency to season crack in brass tubes; possibility of drawing high-brass tubes so as to prevent occurrence of harmful stresses. Bibliography.

TUBES, STEEL

MANUFACTURE. Manipulating Weldless Steel Tubes. *Machy. (Lond.)*, vol. 35, nos. 901 and 902, Jan. 16, 1930, pp. 505-508, and Jan. 23, 1930, pp. 537-541, 21 figs.

Jan. 16: Methods employed by Accles and Pollock, Ltd., Oldbury, in manufacturing steel tubes; rotary piercing operation; pilgering operation; cold-drawing operation; tube butting. Jan. 23: Drawing tubes; with-drawing mandrel; tapering tubes; manipulating seat pillar; tube expanding; doming and beading operations (To be continued.)

News of the Society

THE NATIONAL METAL CONGRESS AND EXPOSITION

THE spacious Stevens Hotel in Chicago will contain all the events of the twelfth National Metal Congress and Exposition, which is scheduled for the week of September 22nd. For the first time in the Society's history, a visitor to the convention will find everything from his hotel room to the exhibits under a single roof.

Approximately 75,000 gross square feet will be devoted to the exposition. The exhibition hall, grand ball room and foyer, main dining room, lounge and writing room will provide the setting for what is expected to be the most attractive show ever sponsored by the Society. No restrictions are imposed as to the type of exhibit, so this year, as before, visitors can see all kinds of furnaces in operation, displays of heavy machinery and the other interesting products which make the National Metal Expositions outstanding.

Convention papers will be presented in still other meeting rooms of the hotel, all conveniently near the exhibition halls but located and designed for privacy and quiet. An interesting program is being arranged by the Meetings and Papers Committee and will be published soon.

The 1930 Campbell Memorial Lecture will be delivered by Marcus A. Grossmann, chief metallurgical engineer of the Central Alloy Steel Corporation, Canton, Ohio, before the annual meeting of the Society on September 24th. Mr. Grossmann's subject has not yet been announced.

THE WESTERN METAL CONGRESS AND EXPOSITION

Plans for the 1931, or second Western Metal Congress and Exposition to be held in the Civic Auditorium at San Francisco the week of February 16th, are rapidly progressing. Floor plans are being drawn and will soon be mailed to prospective exhibitors.

A general committee headed by Ivan L. Johnson, superintendent of the Best Steel Casting Co., Oakland, is handling the local arrangements for the Congress. The other committeemen are Frank B. Drake, president of the Johnson Gear Co., Berkeley; Myron Bird, vice-president, California Saw Works; and R. S. Hirst, Hall-Scott Motor Car Co., Berkeley.

UNAUDITED INCOME AND EXPENSE STATEMENT AMERICAN SOCIETY *for* STEEL TREATING

For the period from January 1 to March 31, 1930

INCOME		
Membership Dues	\$ 53,705.42	
Less—Apportionment of Dues to Chapters	23,782.89	\$ 29,922.53
Transactions—Advertising	\$ 12,609.22	
Subscriptions	1,418.20	

Sales	410.21	
Reprints	321.15	
Bindery	440.50	15,199.28
Books Purchased		778.00
General Index		17.40
Books Published		994.49
National Metals Handbook		299.03
Interest Earned	\$ 299.48	
Discount Earned	184.93	
Sundry Income	128.65	613.06

TOTAL INCOME \$ 47,823.79

EXPENSE

Support of Chapters		\$ 301.62
Transactions		11,728.36
Reprints		266.37
Bindery		421.05
Books—For Library		4.62
Purchased for Resale		468.68
Books Published		858.16
National Metals Handbook		1,241.20
Extension Division		27.84
1930 Convention Deferred Expense	\$ 4,877.74	
Western Metal Show Deferred Expense	1,712.13	
Semi-Annual Meeting		1,228.17
National Committees—Recommended Practice	\$ 1,173.56	
Finance	248.57	
Publications	824.13	2,246.26
Directors		1,505.35
President's Office		161.73
Treasurer's Office		1,572.25
Secretary's Office		6,385.23
General Expense		3,220.15

TOTAL EXPENSE \$ 31,637.04

EXCESS INCOME OVER EXPENSE \$ 16,186.75

BALANCE SHEET

As of March 31, 1930

ASSETS

CASH

Petty Cash Fund	\$ 122.88	
Cleveland Trust Company (Commercial Account)	18,160.83	
Savings Accounts	22,721.42	\$ 41,005.13

SECURITIES

U. S. Government Bonds	\$ 27,689.70	
Other Securities	132,232.38	
Accrued Interest	693.47	160,615.55

ACCOUNTS RECEIVABLE

.....	\$ 5,641.15	
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Less Allowance for Doubtful Accounts	316.63	5,324.52
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Inventory	\$ 10,966.33	
Travel Advances	2,556.14	
Insurance Premiums Prepaid	772.97	
Office Furniture and Fixtures	3,725.37	
Western Metal Show Deferred Expense	1,712.13	
1930 Convention Deferred Expense	4,877.74	

TOTAL ASSETS \$231,555.88

LIABILITIES, RESERVES AND SURPLUS

Accounts Payable	\$ 11,659.59	
Reserves	73,532.48	

SURPLUS

January 1, 1930	\$160,188.06	
Plus—Excess Income over Expense during period from January 1 to March 31, 1930	16,186.75	

.....	\$176,374.81	
Less—Reserve set up for Development..\$30,000.00		
Adjustments for old accounts	11.00	30,011.00
.....		146,363.81

TOTAL LIABILITIES, RESERVES
AND SURPLUS \$231,555.88

ay

2.28
1.00
7.40
4.49
0.03

3.06
3.79

1.62
8.36
6.37
1.05
4.62
8.68
8.16
1.20
7.84

28.17

46.26
55.35
51.73
72.25
35.23
20.15

37.04

86.75

555.88

555.88